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SYLLABUS

OF

A COURSE OF LECTURES

ON

ELEMENTARY GEOLOGY

BY

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INTRODUCTION.

The method of presentation followed in these lectures is not intended to be a strictly logical one from a geological point of view. It is not thought that the logic of the subject as a whole is of any particular importance to the student until he shall have gained a good general knowledge of geological phenomena and of geological principles.

It is the aim to begin with those phenomena with which the average student is most likely to be familiar, and by using this familiarity to branch out so as to cover the whole field, in so far as it can be done in such an elementary course of lectures.

The order of presentation is approximately that followed in the text-books.

The student cannot be too deeply impressed with the fact that, if he is to get a real knowledge of geology, he must go out of doors and see it face to face. No amount of book study, however important and thorough it may be, can take the place of this field study. But neither must books be neglected, for they contain the results of what others have seen and thought.

The foot-note references will enable students to extend their knowledge by reading. These references are not intended to be full, but the papers cited almost invariably mention others upon the same subject, and some of them contain full bibliographies.

TEXT-BOOKS OF GEOLOGY.

MANUAL OF GEOLOGY. By James D. Dana. Fourth edition, New York, 1895. 1087 pages. Price, $5.00.

AN INTRODUCTION TO GEOLOGY. By W. B. Scott. New York, 1897. 573+xxvii pages. Price, $1.90.

TEXT-BOOK OF GEOLOGY. By Sir Archibald Geikie. Third edition, London and New York, 1893. 1147+xvii pages. Price, $7.50.

PHYSICAL GEOLOGY. By A. H. Green. London, 1882. 728+xxiv pages. Price, $6.00.

GEOLOGY, CHEMICAL, PHYSICAL, AND STRATIGRAPHICAL. By Joseph Prestwich. Oxford, 1886. 2 vols., 1083+lii pages. Price, $15.00.

PRINCIPLES OF GEOLOGY. By Sir Charles Lyell. Eleventh edition, 2 vols., New York, 1889. 1323+xxxix pages. Price, $8.00.

TRAITÉ DE GÉOLOGIE. Par A. de Lapparent. 2me edition, Paris, 1885. 1504+xv pages. 4me edition, Paris, 1900. 3 vols., 1912+xxiii pages. Price, $10.00.

THE STUDENT'S HAND-BOOK OF PHYSICAL GEOLOGY. By A. J. Jukes-Browne. London, 1884. 514+xii pages. Price, $2.40. New edition, London, 1902.

ELEMENTE DER GEOLOGIE. Von Dr. Hermann Credner. Leipzig, 1887.

Introductory statement of subject in general. (See C.+S. Preliminary outline)

Geology - the study of the history and structure of the earth.

Divisions - (1) Astronomic geol. = relations it sustains to sun
(2) Cosmogony = material of earth (Petrology)
(3) Structural = architecture of earth
(4) Physiographic = study of topography & its development
(5) Paleontology = study of fossil forms
(6) Historical Geol = study of historical development
(7) Stratigraphic = " relations & succession of beds
(8) Dynamic = study of geologic agencies
(9) Economic = Geol. in its commercial aspects - ores, soils, water &c.
(10) Atmospheric =
(11) Glacial

Earth dependent upon sun for most of heat and light
Hence for most of its activities on outer surface.
is $\frac{1}{300,000}$ mass of sun.
Energy of earth interior not due to sun.
Nebular theory of earths origin
Meteorites
Falling to earth - possible past importance in growth of earth -

Constitution of the earth -

(1) atmosphere
(2) Hydrosphere
(3) Lithosphere

(1) Atmosphere = 79 N, 21, O, .0003 CO_2, water vapor, (vol. gases) & such other substances as will not be liquid or solid at ordinary temperatures.

Dense at surface (15 lbs per sq. in.) thinning upwards to unknown heights. Molecules shooting about according to law of gases, as get away from earth, are turned back by gravitation. Any of em that get 620,000 miles away will go on to sun, by gravitation

Atmosphere while acting as a geologic agent acts also as a thermal blanket over the earths surface.

Mass of atmosphere figured at $\frac{1}{1,200,000}$ that of earths.

(2) Hydrosphere: 1300 quadrillion tons of water, $\frac{1}{4540}$ of mass of earth, lies in the oceans, rivers, lakes, and in outer crust.

↑ This water is the most active of all the geol. agents.

↑ The oceans cover @ 143,259,300 sq. mi, 10,000,000 sq. mi. of this lies on the continental shelf. averaging only @ 600 ft deep.

↑ The greatest ocean depths are @ 30,000 ft.

(a) Irregularities continental plateaus + ocean basins
If water covered whole (i.e. if continents were dumped in basins) it would be @ 9,000 ft deep.
Ocean basins contain broad undulations
Land surfaces have volc. peaks + slumps + broad folds, plateaus +c, but these have all been greatly modified by erosive agencies.

(b) Surface or lithosphere.
A thin "skin" of surface soil, clay, sand, + rock fragments, derived from the solid rock crust. Sometimes soil mantle is lacking exposing the solid crust.
The loose soil is being constantly formed and as constantly moved on towards the sea.
Glaciers, also have had much to do in the formation and moving of surface rock + soil - eg. N. N.A. + N.W. Europe - also Greenland, today.

(C) Crust of lithosphere. Everywhere beneath the soil. As soil, clay, sand, gravel +c. is carried down by streams + dumped in sea or lakes it is more or less sorted, + deposited in layers. These harden to stratified rock, and again become a part of the outer crust of the lithosphere.
By the crust of the lithosphere we mean that portion we see, or can have some positive evidence about. There is probably only solid rock on down.

(d) Interior of the deep interior of the earth we know practically nothing.

The solid part then consists of (1) loose surface material a few feet to a few hundred feet thick, (2) a zone many thousands of feet thick of rock, such as we know, (3) a central mass we know nothing about [illegible]

ELEMENTARY GEOLOGY.

THE DATA OF GEOLOGY.

Geology has to do with the structure and history of the earth.

Geologic reasoning is based on the supposition that the operation of geologic agencies is constant under given conditions.

Geology deals with two classes of phenomena:

I. OBJECTIVE PHENOMENA, or the materials, structure, and forms of the earth. These phenomena are:

1. *Rocks and their constituents.*

The earth is made of rocks.

Geologic definition of rocks.

The rocks are made of minerals.

Examples of different kinds of rocks:

Conglomerates, pebbles, pudding-stones, sands, sandstones, clays, shales.

Igneous rocks.

2. *Structural features*, or the internal conditions and changes of the rocks.

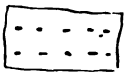
What is meant by the earth's structure.

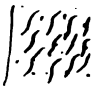
Examples exposed in cañons, gorges, gullies, road and railway cuts, mines, tunnels, and wells.

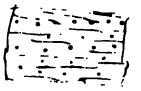
Conventional signs usually used in design
sections +c.

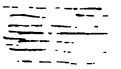
Conglomerate =

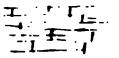
Limestone

Sandstone = 

Clay. Soil +c. 

Shaly S.S. or Silicious shale = 

Shale = 

Calcareous Shale = 

Granite + Syenite → or Colored →

beds - grand Canon, +c
cd - Hard and soft - folio
d - soft - folio.
ted - soft - folio.
us - Bidwell bar folio.

(Introductory statement continued from p 4C.)

Two great classes of rock -

(1) Stratified - or derived.

(2) Unstratified (or crystalline) - igneous - granites &c.

(1.) Stratified rock

Characters - (a) Sands - sandstones -

(b) Clays - shales -

(C) Pebbles - conglomerate

(d) Shells, (Calcareous) limestone

combinations of these.

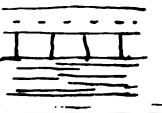
These are often greatly changed by heat and other agencies - or become metamorphic rock.

The stratified rock contain fossils, which record the development of life upon the globe.

Such rock originally deposited beneath the sea and afterwards raised above it, where we can observe them, furnish the chief pages in the earth's history.

Unformity When lying in perfect succession such rocks are said to be conformable.

a.b.C. are conformable



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(2) The Crystalline rox: Igneous + metamorphic -

While the stratified rocks cover about ⅔ of the land surface
are everywhere underlain at no great depth - (a few th
feet, or a few miles) by the igneous or metamorphic

The black line shows @ the relative thickness of t
stratified rox over a 1000 mile sec. zenith - Chamberlin + Sal

Relations of igneous rox to sedimentaries - various

Four great sedimentary eras. (1) ~~Cenozoic~~
(1) Cenozoic = recent life
(2) Mesozoic = middle life
(3) Paleozoic = old life
(4) Proterozoic = earlier life - life must have prevailed, but little is known about it - most of rox metamorphosed + re of fossils destroyed.

Below the above is the (5) Archean complex - mostly me morphosed igneous rox, but some sediments, extending to unknown depths. W as probably life during period - but rox every where marked, sheared, contorted, so fossils are generally destroyed.

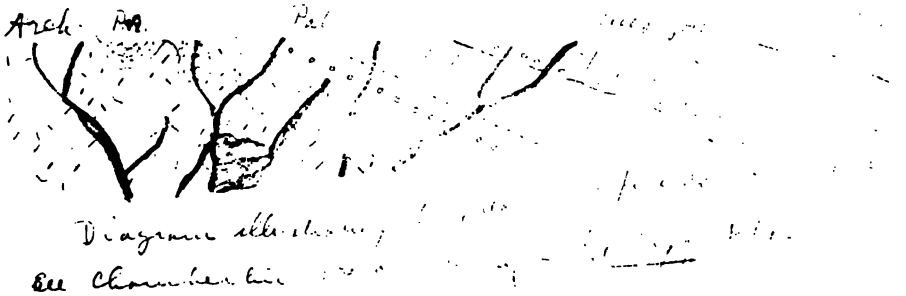


Diagram illustrating

See Chamberlin

In order to understand the forms, we must understand the structure; to understand the structure, we must understand how the rocks are made and modified.

That branch of geology which deals with the topographic forms and surface features of the earth, their origin and modification, is called *Topographic Geology*, or *Physiography*. It will be treated of in Part IV.

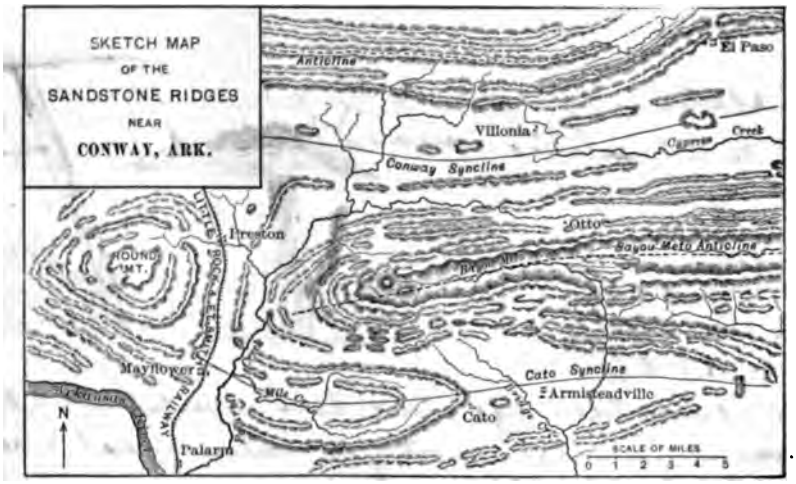
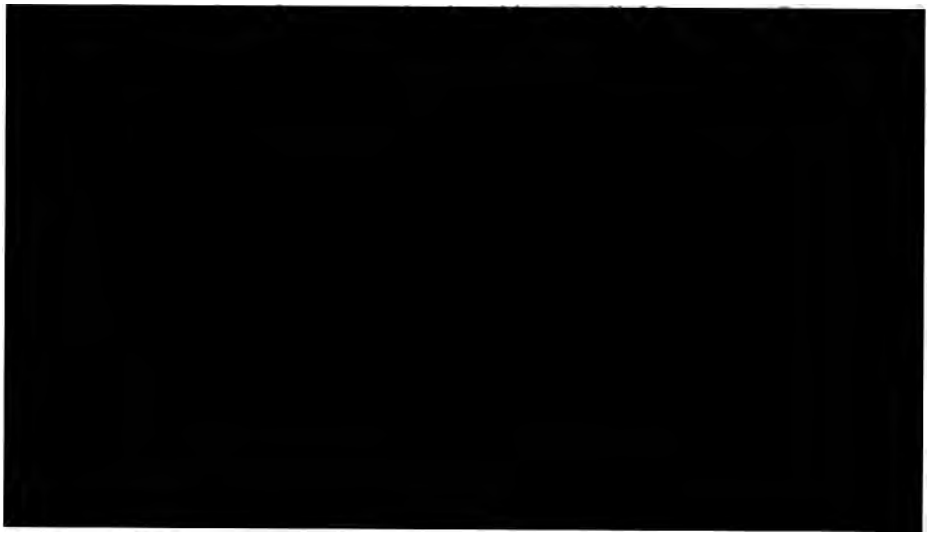


Fig. 2.—Example of parallel ridges and valleys due to folding and denudation of alternate hard and soft layers of rock. (Means.)

II. Subjective Phenomena, or the processes by which those materials of which the earth is formed have reached their present conditions.



PART I.

DYNAMICAL GEOLOGY.

Dynamical geology is that branch which deals with rock-making and rock-destroying agencies. Rocks may be classed as—

1. *Mechanical sediments*, or rocks deposited mechanically, either by air or by water. They are usually called sedimentary rocks.
2. *Chemical deposits*, or precipitates from solution in gases or in water.
3. *Igneous rocks*, or those cooled and hardened from a fused condition.
4. *Rocks of organic origin*, or those made by accumulations of organic matter.

These embrace all the kinds of rocks in all parts of the globe.

All rocks have peculiarities or characteristics due to the methods of their formation. It is, therefore, necessary to understand these methods or agencies, in order to know how and under what circumstances the rocks were formed.

GEOLOGIC AGENCIES.

THE DIRECT WORK OF THE ATMOSPHERE.*

The work of the atmosphere is called æolian, and the deposits are known as æolian rocks.

The direct geologic work of the atmosphere in done chiefly in arid regions and on sandy shores. It consists of *carrying*, *wearing*, and *depositing*.

I. The Carrying Done by the Wind.

Distribution of volcanic dust or cinders.

For miles around Mount Shasta; Vesuvius; wide-spread tuff beds of Arizona.

In Iceland;† in South America.‡

In August, 1883, eruption of Krakatoa, in Straits of Sunda; ashes fell nearly 1,000 miles southwest of there.§

Skies made red all over the world, till November of that year, by the fine dust,‖ which rose to an elevation of 85,217 feet in Venezuela, and 106,250 feet at St. Helena.

Dust- and sand-storms ¶ are common in arid regions, but they also occur in regions that are not arid.**

Burying of roads and railway tracks.

Filling of railway cuts; wind-breaks.

Burial of forest on the shores of Lake Michigan.

Burial of farms of west Portugal; Bermuda.††

In Asia and Africa towns and cities have been buried.‡‡

In the Argentine Republic dust produces darkness and obliterates landmarks and roads.*

Darkness caused by mineral matter in the air.†

Estimated that such storms carry at least 2,000 tons to the cubic mile.‡

In April, 1863, several inches of dust fell at Peking, China; it came from the cultivated fields of Asia.§

In February, 1898, worn sand, probably from Sahara, fell on shipboard nine hundred miles off the coast of Africa.‖

Distribution of plants by seeds blown over the earth.¶

Seeds with wings, etc. "Tumbleweed."

Russian thistle.**

Diatoms.

Distribution of animals.

Birds, blown out to sea.

Spiders, locusts, butterflies.

Origin of insular floras and faunas.††

Influence of plants and animals upon geology.

II. The Wearing Done by Wind.

Wind alone does not wear rocks; it wears with what it carries.‡‡

Effect of the impact of single particles.

Dulling of car windows in arid regions.

Wearing through of glass panes near dunes.

Wearing and rounding of telegraph-poles in deserts.

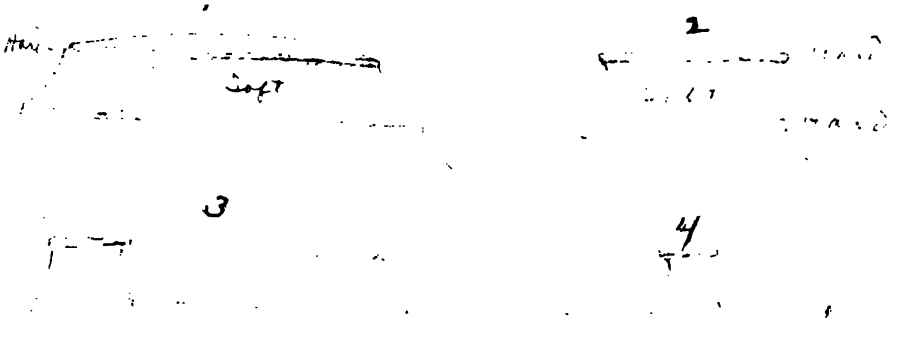
Polishing of rocks in mountain passes.§§

Faceting of pebbles.‖‖ Examples.

Effect upon vegetation.

Toadstool-shaped rocks supposed to be so made; often due to softer layers.¶¶

Origin of the sand-blast used for grinding and ornamenting glass, stone-carving



Note action of sand in greatest ground, for heaviest sand stays there -

---

6 Very hard, fine grained rock worn by sand with difficulty. Rock with hard + soft spots wear much faster - soft spots wear out + rock crumble.

---

7 Note effect where rock, being worn away are protected by hard concretion or other substance. Note effect of hard layers. Specimen

---

(8) The great dust fall of Feb. 1903, + its origin, by H.R. Mill and R.G.K Lempfert Quart. Jour. Royal Meteorolog. Soc. Vol XXX, pp 57-88.

Dust fell over most of England + Wales. Origin unknown.

III. The Depositing of Wind-Borne Material.*

Why wind-borne material is deposited:
If volcanic dust falls in water, or is bedded, it makes tuffs.
If rain falls through dust, it falls as mud.†
Wind-blown sands make dunes.

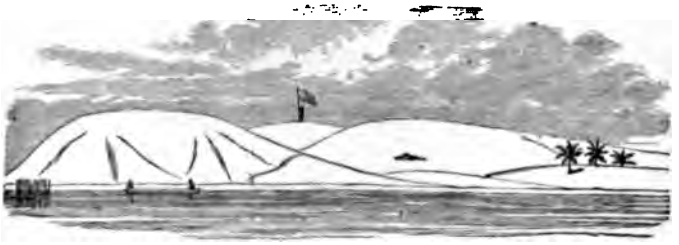


Fig. 3.—Sand-dunes on the Sergipe coast, Brazil. (Hartt.)

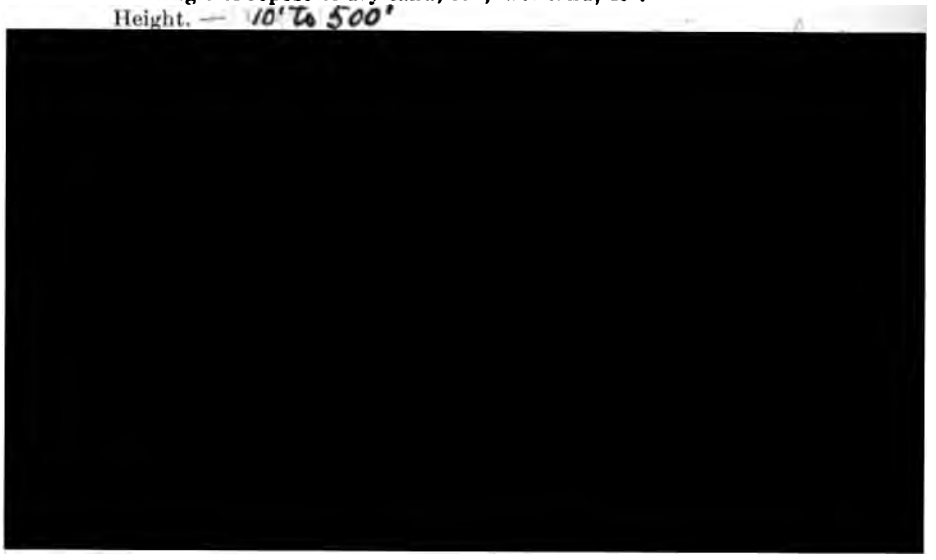
Formation and shifting of sand-dunes.‡
Movement of dunes; burial of houses; invasion of towns and forests;§ dune helped across a railway.‖

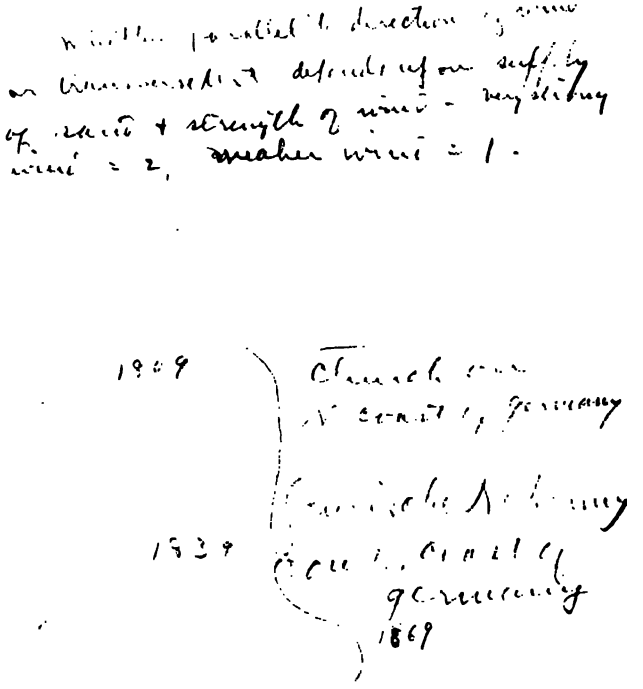
Forms.

1. Lines at right angles to wind in unobstructed regions.
2. Lines parallel with winds in regions of isolated obstructions, such as bushes.

Angle of repose of dry sand, 35°; wet sand, 40°.

Height. —





Structure.
  Due to methods of deposition.
  Variations produced by shifting winds.
Length.
  Examples: Monterey, southwest France, Holland.*
  Damming of streams on west coast of France and in northeast Brazil.†

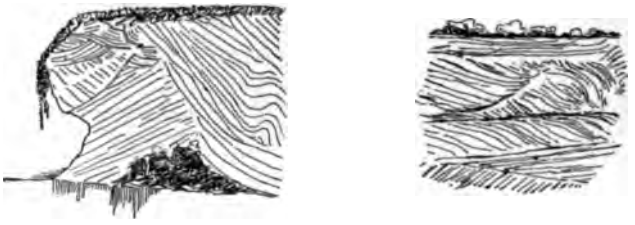


Fig. 4.—Sand-dune structure exposed in æolian sandstone.

Æolian rocks.

Æolian rocks are those formed of wind-blown materials, usually sands.
  They are not necessarily different from other sandstones.
Mostly of quartz sand.
  In Carson Desert, Nevada, dunes of minute crustacean shells.
  Near Fillmore, Utah, of gypsum.

1. Dunes constantly changing form with each change of wind. Causing cross bedding & various contortions & complications of bedding. Their surfaces often show ripple marks.

Bermuda* and Bahamas made of æolian calcareous sandstone.
Process by which such rocks are hardened.
Supposed æolian origin of the loess of China; 2,500 feet thick.†
Cut by streams into gulches 30 to 100 feet deep and 4 to 20 feet wide; houses cut in these walls.
Influence of vegetation on æolian deposits.‡
Probable origin of the "hog-wallows" of the San Joaquin Valley, California.§
Similar phenomena to be seen in most deserts.

INDIRECT WORK OF THE ATMOSPHERE.

The indirect work of the atmosphere is more important than its direct work. It may be included under the following heads:

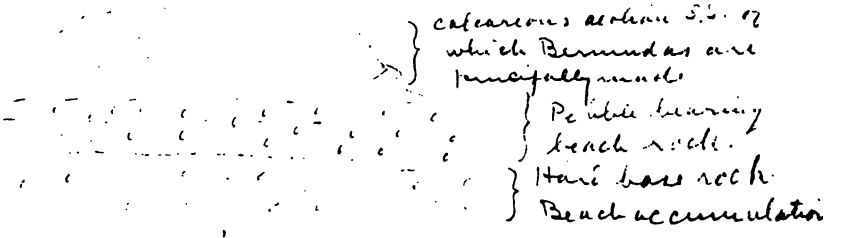
1. Changes of temperature.
2. Evaporation.
3. Production of waves on large bodies of water.
4. Effect on the water level.
5. Effect on ocean currents and climates.
6. Its work as a water carrier.

I. Changes of Temperature.

All changes of temperature cause rocks and minerals to contract and expand. In massive or crystalline rocks the crystals expand and contract differently along their different axes. Some even contract along one axis while expanding along another.‖

The rocks are composed of several minerals interlocking; the expan-

(1)


calcareous sediments 5% of which Bermudas are principally made
Pebble bearing beach rock.
Hard base rock
Beach accumulation

Bermudas - 100-200 ft (cm) number of traces of volcanic - extinct only few feet above sea - highest @ 150 ft -

(2) Iron lime or Silica Tubes ... by percolating water at top of deposit - ... down through ... porous sand H_2O evaporates & ... matter consequently fill - cementing deposits

Example of Barrier Reefs of Brazil - ... formed & how hardened - See p. 135 paper on ... tions - ppt caused by fresh & salt water mixing together in the spits of barrier beaches -

Changes of temperature affect surface layers especially.

This produces spalling, chipping, and exfoliation in layers.

Tendency to produce rounded blocks; reason for the rounding of corners.

Rounding of basaltic columns; examples.

Called "boulders of decomposition."*

Same effect produced on hills and mountains of massive rocks noticeable in granite region. Examples: Yosemite Valley, Serra do Mar, Rio de Janeiro, interior of Africa, Georgia,† and North Carolina.‡

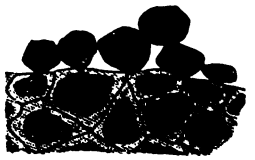


Fig. 6. The weathering of massive rocks along joints and the formation of boulders of decomposition.

Granite and gneiss expand one part in about 200,000 for every additional degree at ordinary temperatures.

Annual change in temperate regions is about 150° (—25° to +125° Fahr.) for exposed surfaces.

Linear expansion for 103° over a surface of 300 feet = 1.85 inches.

(1)

(2)

3.

[redacted]

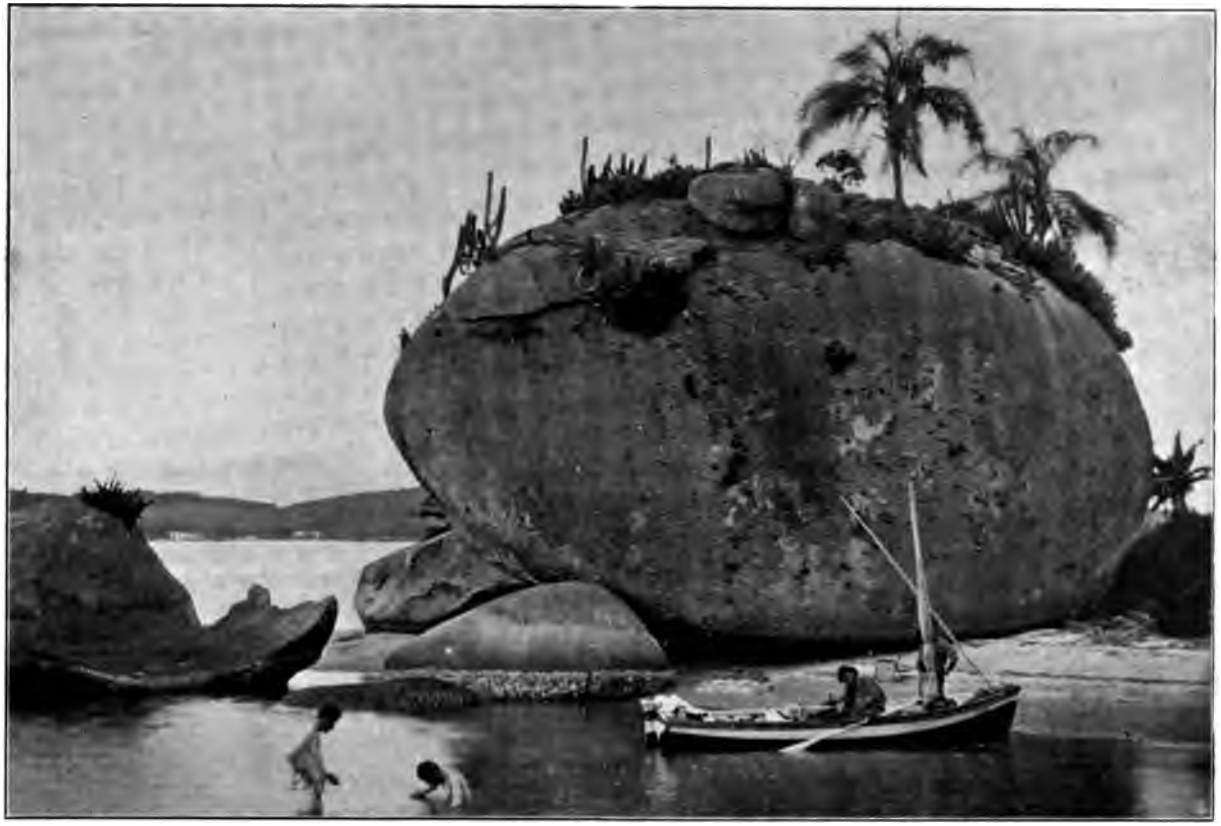


Plate I. — Exfoliated granite boulders of decomposition at Ilha d' Agua in the Bay of Rio de Janeiro. (Ferrez.)

Rifts found in granite quarries caused by this expansion and contraction.* (See Plate II.)

When the temperature falls below freezing another set of phenomena is introduced by the expansion of water on freezing,

Lifting of sidewalks.

Crumbling of damp earth by needle-ice.

Enlargement of crevices in rocks.

Throwing down of loose fragments and blocks from cliffs.

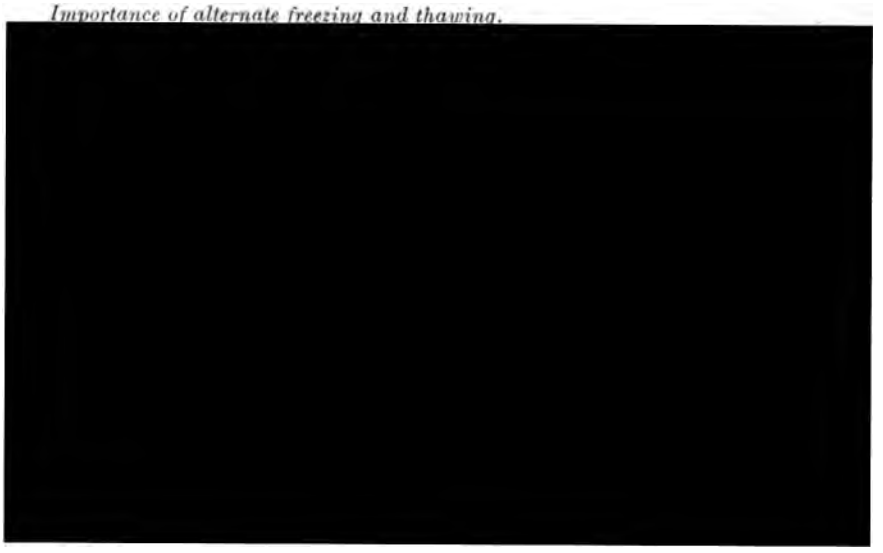
Case of Cleopatra's Needle in New York City.

Formation of talus slopes.

Disintegration of porous rocks.

Fig. 8.—A granite peak rounded by exfoliation, Victoria, Brazil. (Hartt.)

Importance of alternate freezing and thawing.



(1) Note - Shelving of Chapultepec sandstone, in N.Y.

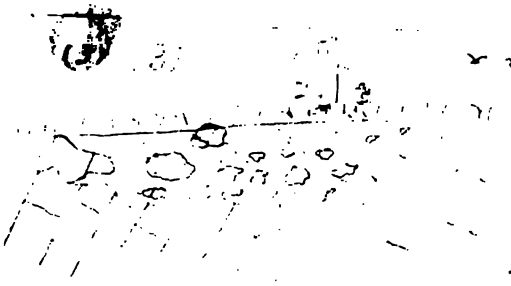
(2) Creep due largely to freezing & thawing combined with gravitation

20 ÷

North.

Rock in Place

Soil



See also Penrose' figures Plate IV.

Figure to show formation of soil in place, & transition from soil to rock.

Depth to which such decomposition may extend + thickness of soil resulting if it is not removed by water or wind - eg. in Brazil

Plate II. — A granite quarry near Little Rock, Arkansas, showing sheets of exfoliation caused by expansion and contraction.

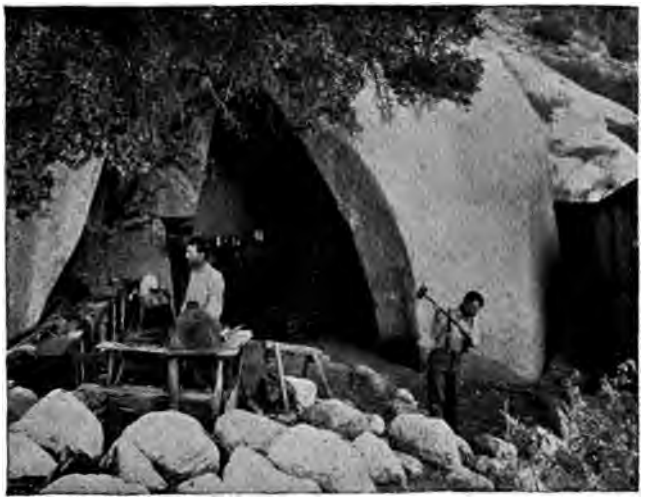


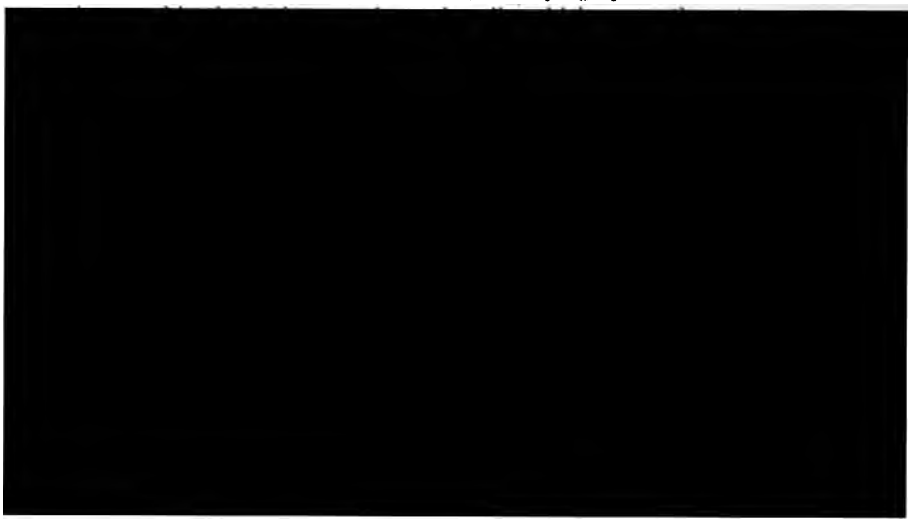
Plate III. — A cave room, made by the exfoliation of granite, in San Jacinto Mountains, Riverside County, California. (McMillan.)

Why some blocks of rock are left undecayed.*
Why soil is often thin on slopes and deeper in the valleys.
Alluvial soils derived from residuary soils.
Method of accumulation.
Origin of soil belts.
Glacial soils are derived largely from residuary soils.
Accumulation and modification.†

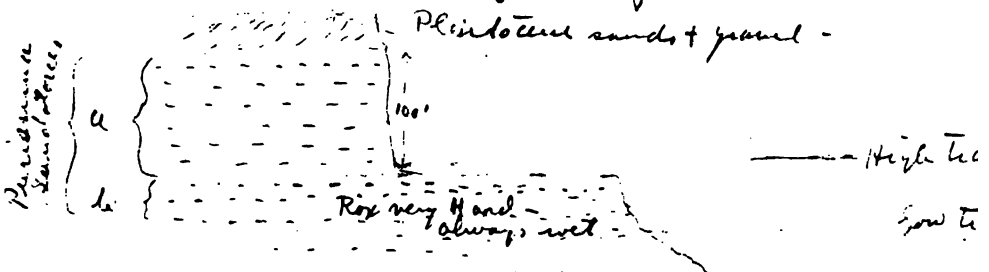
Fig. 9.—Talus slopes on the side of Mount Sneffels, Colorado.

II. Evaporation.

The geological work of evaporation consists in the concentration and deposition of minerals dissolved in water, the drying up of streams in arid



(1) Importance of drying out: Slacking of rock especially slates + muddy S.S., before drying - eg. sea shelves along coast @ Penmaenmawr, + W of Stn Cmg.



section showing protective influence of water in rock, kept continually wet. S. of Penmaenmawr Ca a + B are identical in composition & (along dotted line) remains wet + hard + resistant all the time a dries out, slacks + crumbles down, being then easily attacked by rain wind, + such waves as reach it during highest tides + heaviest storms.

Effect of this inland where cut by streams.

Photos of Revolutions

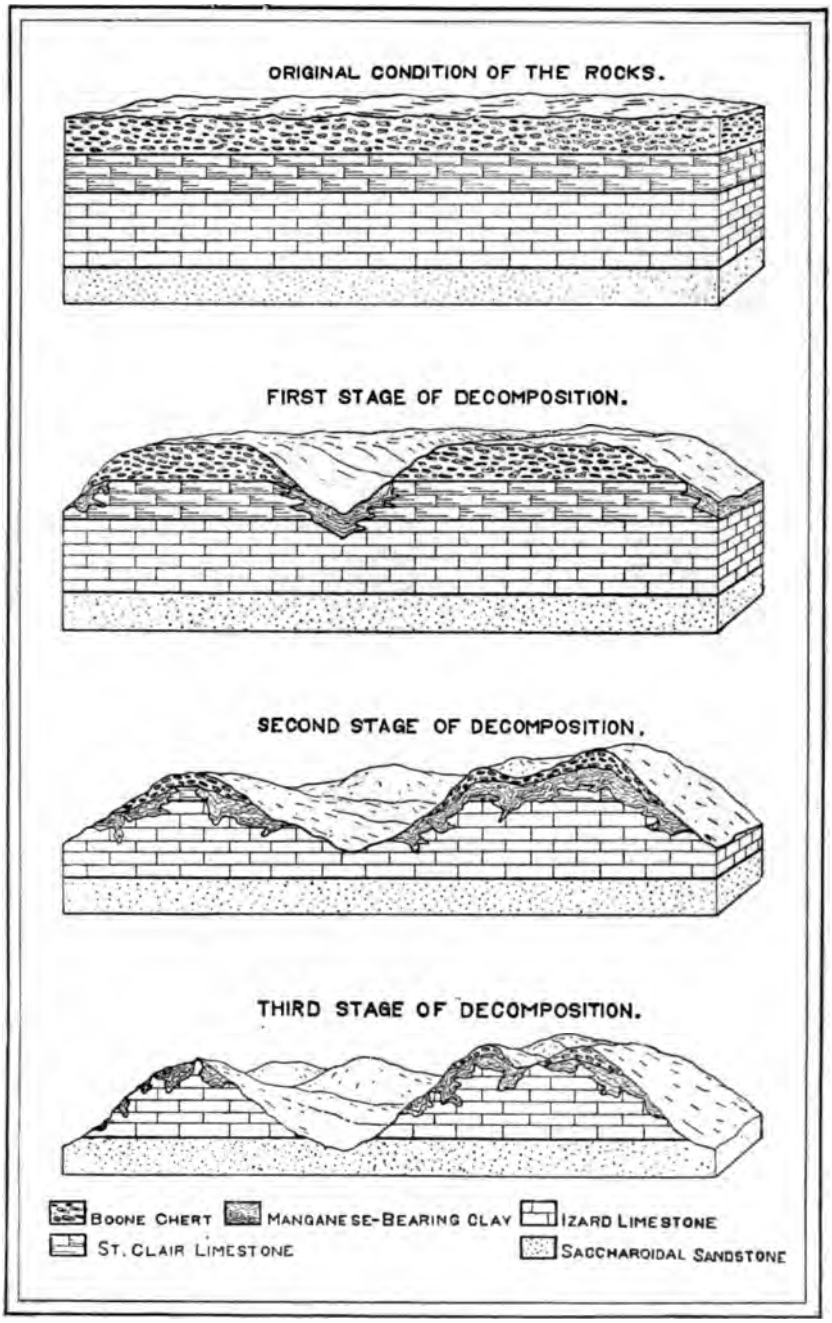
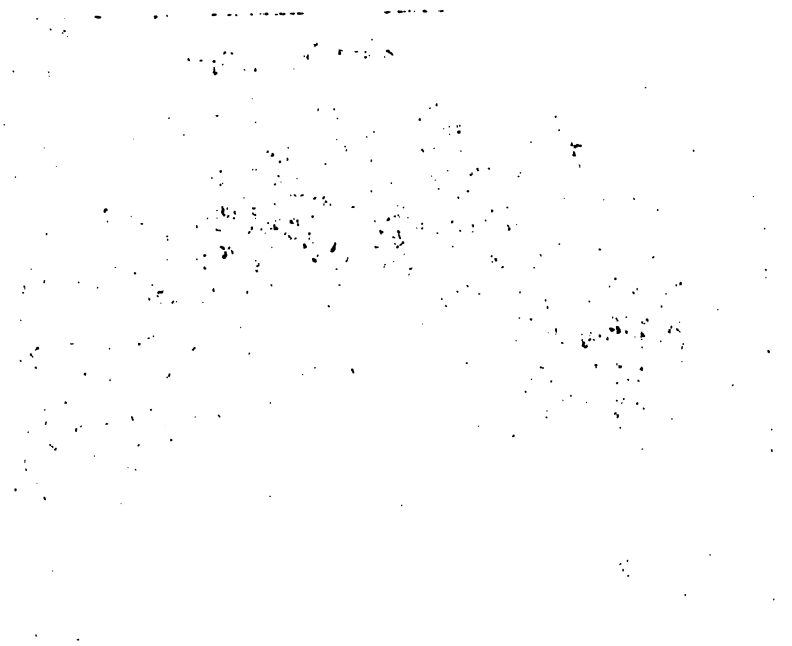


Plate IV. — Theoretical sections showing the process of irregular rock decomposition and the formation of soil. (Penrose.)



All spring, well, or surface waters contain mineral matter in solution. How demonstrated.

Water passing through rocks and soils dissolves some of the soluble minerals. In arid regions surface evaporation causes water to come to the surface from below or within, and its evaporation leaves the mineral in small crystals over the surface. Called "alkali"; various substances, such as sulphate of magnesia, sodium chloride, etc.*

[redacted]

(1) Ark River water contains 1.69 to 231 grs per
U.S. Gallon 1887-1888 Ark river carried
6,828,300 T of matter in Sol. past Little Rock.

[redacted]

Efflorescence often causes rock surfaces to disintegrate and cavities to form.

Efflorescence, being soluble, is washed off by rain.

Origin of the "whitewash" of brick buildings.

III. Production of Waves on Large Bodies of Water.

Waves are one of the most important geologic agents.

Most waves are produced by wind moving over water.

The geologic work of waves is done at the shore line.

If water were undisturbed it would not cut land.

(The geologic work of waves is treated at length under the head of Aqueous Agencies.)

Abruptness of sea and lake shores due chiefly to the undercutting of waves.

Skeleton islands off coasts and attacked shores.

Transportation of shingle and sand along shores.

Formation of spits. (Discussed under Aqueous Agencies.)

Fig. 11.—Streams near Oceanside dammed by beach sands heaped across their mouths.

Damming of river mouths by wave-driven sands. Example: Oceanside,

Tides are unusually high when the wind helps.

Effect of southeast winds on the tides in the Bay of Fundy.*

Higher tides increase the range of wave-cutting.

V. Effects of Winds on Ocean Currents and Climate.†

Character and direction of ocean currents.

Ocean currents are produced partly by the lagging of water on the revolving globe.

The atmosphere as a whole lags in much the same way, but, being heated at the equator, it rises and flows toward the cold poles. This produces currents in contact with the globe, chiefly a water surface, which, as they move toward the equator, lag, and hence swing westward.

These air currents help on the ocean currents which tend to pile up the water. In the Gulf of Mexico it escapes as the "Gulf Stream" into the North Atlantic.

Probably only the surface currents are determined by winds, while the deep currents are due largely to convection.‡

In 1882 severe northwest gales pushed aside the warm gulf waters off the New England coast, and the coldness of the waters killed the tile-fish by the millions.§

Climatic effect of the warm waters carried into polar regions.

Example of northwestern Europe and Iceland.

VI. The Atmosphere as a Water Carrier.

The air is never still.

The great air currents are more or less definite, but they are influenced

When the temperature into which the water-laden air is brought *is below freezing* the precipitation is frozen — that is, it is in the form of frost, hail,* or snow.

Frost on window-panes, instead of water, when it is freezing cold on the pane.

Why there is snow only about the poles and on the highest mountains.

Why there is usually no snow in the coldest weather.

Sleet and hail start high and freeze before reaching the earth.

Importance of water to life.

Water is one of the first conditions of existence: no life without it.

The most important geologic work done by the atmosphere is that which it does as a water carrier.

All the geolgic work done by water is indirectly the work of the atmosphere.

Of the atmosphere in general.

The exposure of rocks to the air is fatal to the rocks.

They are almost universally broken up and destroyed.

They can last only when protected from the atmosphere.

Rock destruction is chiefly a subaerial process.

MECHANICAL AQUEOUS AGENCIES.

The mechanical work of water is done by—

1. Rain (in its direct work).
2. Streams.
3. Lakes.
4. Seas and oceans.
5. Ice in forming and as glaciers and icebergs.

I. The Mechanical Work of Rain.

Most of the mechanical work of rain is done after the water gathers in streams.

The impact of rain, however, produces certain peculiar topographic forms, illustrated by the stone-capped columns, or earth pillars, of Tyrol,* and of La Paz Valley, Bolivia.†

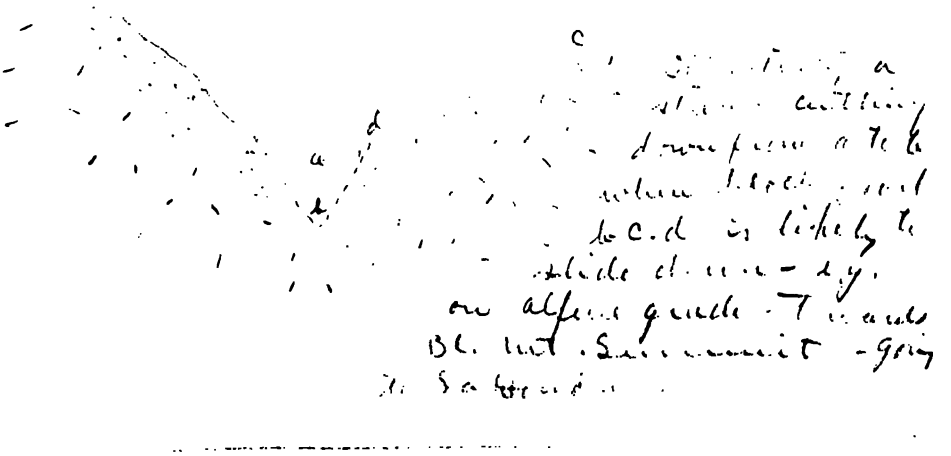
Aside from that which evaporates, the water of rain *runs off as streams* (p. 38), or *soaks into the ground* and emerges as springs, either on land or beneath the ocean.

Landslides, or landslips.

Landslides are mechanical effects produced by rain-water soaking the ground.

Common in railway cuts, and wherever the natural support of the soil has been removed.

(1)



Conditions favoring landslides:

1. Topographic form; only in mountains and hills.
2. Geologic structure.
3. Mineralogic composition.

   Clays, kaolin, decayed shale, serpentine, steatite, soapstone, graphite, mica, and peat are all slippery when wet.

4. Water present.*
5. Earthquakes.†

How to prevent landslides.

1. By draining and turning the water away from the slippery earth.
2. By planting trees where roots will hold the soil.
3. By protecting the natural supports of land liable to slip.

   Case of the reservoir at Rio de Janeiro.

II. The Mechanical Work of Streams.

Origin of streams.

Relation to underground water supply.

Relation to surface waters.

The mechanical work of streams.

1. Erosion, or wearing.
2. Transportation, or carrying.
3. Deposition.

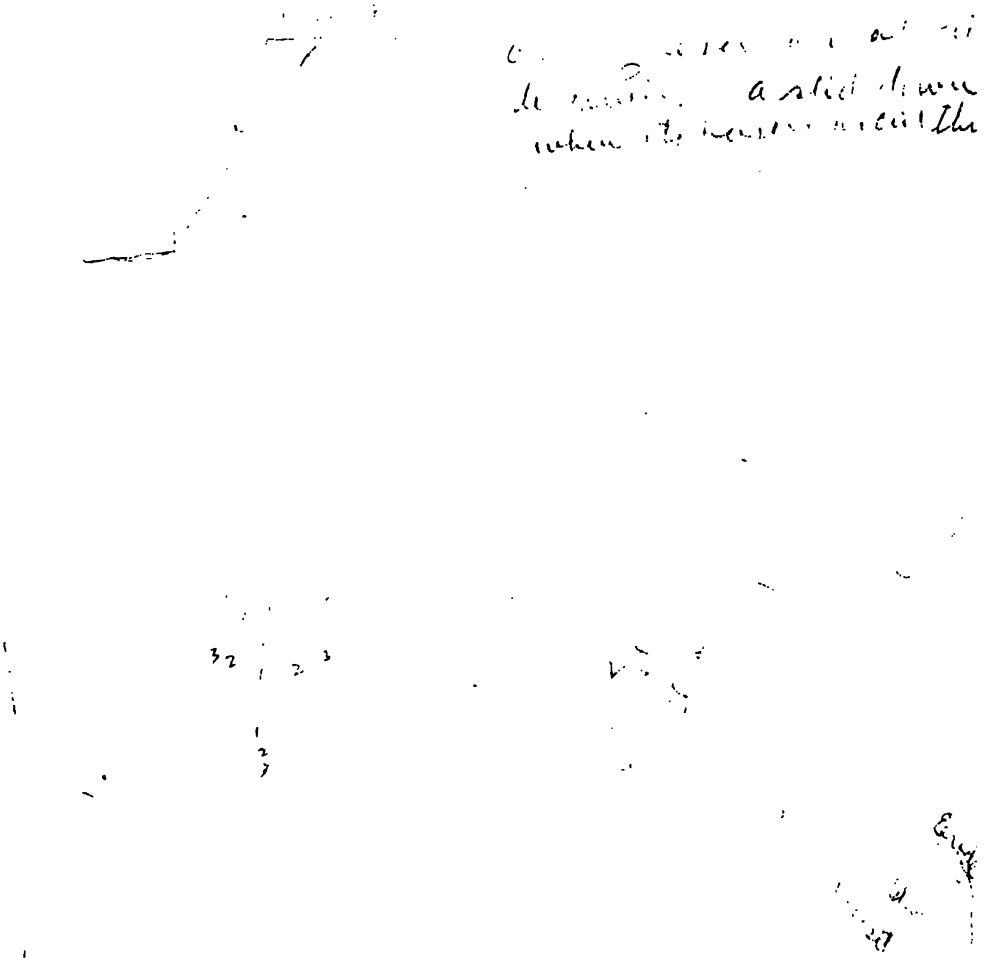
The whole process of removal is generally spoken of as *denudation*.

The laws of flow in open streams.

Different rates of surface, bottom, and sides of streams.

Different rates at bends.

Difference due to internal friction as well as to friction against the channel.‡



Lateral erosion undercuts banks of soft materials.

Centrifugal force on the outside of a stream's curves.

Lateral erosion operates chiefly in the lower part of a river's course.

Produces winding streams.

Swinging of streams from side to side.

Ox-bows and "cut-offs" of the Mississippi River.

Mompox, an old Spanish city, fifty years ago stood on the bank of the Rio Magdalena. Owing to the shifting of the stream it is now twenty miles from that river.*

An old adobe town that formerly stood on the banks of the Colorado river below Needles is now (1902) five miles inland. The falling of the undercut river banks may be heard all night. (V. L. Kellogg.)

Terras cahidas of the Amazonas.†

Formation of river terraces. (See under Physiography.)

II. *Erosion by scour, or abrasion* (of bottom and sides), by transported materials.‡

Materials moved:

Blocks, Cobbles } Boulders.

Pebbles.

Sand.

Clay.

Effects of moving stones and sand.

Clear, clean water cannot cut hard rocks mechanically.

1. *To grind rock beds and sides of streams.* (Abrasion.)

In eddies below cataracts and falls, form *pot-holes.*

Methods of grinding.

Searsville Creek.

(1) Deflection of the Mississippi. by Isaiah Bowman, Science N. Series, Vol. XX, pp 273 – 277

Islands often gradually shifted down stream by cutting away upper end + deposition behind lower end. Hunt.

2. *To bump together the materials moved.* (Corrasion.)
Process one of wearing, chipping, and rounding.*
Illustrated by the manufacture of playing marbles.†
Pebbles and boulders are rounded in the same way.

Rounded worn pebbles are made only by the action of water as streams or waves.

Why some pebbles are round, some flat, and some long and slender.

How water-worn stones throw light on the history of rock beds.

Rounding of sand grains can be produced only when the current is not strong enough to suspend the grains, but yet strong enough to move them. This allows them to bump over each other like pebbles. Very fine sand is angular.

Size of sand grains in relation to form.

Specific gravity.

Hardness prevents rapid wearing.

Distance traveled.

Agent of transportation,* wind, water, ice.

The power of a stream to wear its channel is increased or kept up by the removal by the current of the material thus produced.

II. Stream Transportation.

Muddy color of some streams, and milky color of glacial streams, due to matter carried.

Law of the transporting power of water:—

Erosive power, or *power to overcome cohesion*, varies as the velocity squared.

That is, velocity doubled quadruples the force of the current.

Transporting power, or *power to overcome weight*, varies as the sixth power of the velocity.

That is, double the current and it will move sixty-four times as big a block.

Or, increase the velocity ten times and it will transport a block one million times as large.†

The total result of these varying carrying capacities is *the sorting action of water*, and the deposition at separate places of coarse and fine materials. Importance of the varying currents caused by fluctuation in the volume of water during freshets.

In regions of concentrated rainfall the stream work is likewise concentrated—very large part of the time, and *nil* the rest of the year. The materials carried mechanically by streams are mostly submerged.

Some streams upon swelling, especially in arid regions, carry sand and small stones upon the surface of the water, held up by tension.*

Determination of the amount of transportation by streams.

I. *By reconstruction or restoration of the topography*, or of matter removed.

In cañons of horizontal rocks. In folded regions by restoring the arches and folds. Of limited application owing to ignorance of the upper limit of the surface removed.

Only part of the record preserved.

II. *By measuring the discharge of drainage*, and estimating the amount of sediments carried out.

Origin of the silts of any stream.

Relations to its hydrographic basin.

Observations on the amount carried in each gallon, and the number of gallons discharged.

Method of measuring discharge.†

Collecting samples at various depths, and in various parts of the stream.

Objects of the method.

Illustrated by work on the Arkansas river.

How to determine the amount of silt in discharge.

The Arkansas river in 1887–88 carried 2 grains of silt per gallon at the lowest stage, and 713 grains per gallon at the highest stage.

(1) The Passaic Flood of 1903. by Marshall and Leighton. U.S. Geol Survey. Water supply and irrigation Paper No. 92 - 1904

Amazon basin 2,264,000 square miles. Drainage is not always proportional to the area. Amazon hydrographic basin has twice the area of Mississippi and five times the water, owing to greater rainfall under the tropics.

The rate of mechanical erosion by streams depends on —

1. The volume of water. Small stream cannot carry much.
2. The slope of the land, which determines the velocity of the streams.
3. Character of the rocks. The softer rocks are cut faster.
4. Quality and quantity of detritus, or load. The hard rocks cut faster; too much chokes up or overloads the stream.
5. Climatic conditions. Differences between dry and wet climates, and especially difference between a region of concentrated rainfall and one having the same rainfall distributed throughout the year. Differences between tropics and cold climates. Freezing loosens soil and rock.

The results of erosion and transportation are local and general.

I. Local Results.

The local result of erosion and transportation is to produce gullies, channels, gorges, waterfalls, and valleys. The smallest ones we see made; larger ones take more time, but the process is the same. The Colorado cañon, a most striking illustration, is 2,000 to 6,000 feet deep.

The Colorado river rises in the Uintah and Rocky Mountains in rainy areas, but it flows through an arid region where there is but little frost to break up, and but little rain to wash down the banks.

Origin of waterfalls.

Waterfalls are necessarily in stream channels.

1. Hanging valleys - See J.C. Branner paper on the hanging valleys of the Yosemite, Journal of Geology.

also

Hanging valleys of the finger lake region of Central New York by Ralph S. Tarr. Amer. Geologist, May 1904 pp 271-291

II. General Results.

The general result of erosion and transportation (or of denudation), as distinguished from the local result, is a lowering of land surfaces.

Demonstrated in cases of large streams.

Origin of the silts carried by streams.

They come from the whole basin, though some parts are attacked more rapidly than others.

Every part of the land above water is attacked by agencies of decomposition and denudation.

The present contour of the land reveals little or nothing of its original form.

The base level of erosion or peneplain.*

III. Deposition.†

Deposition by a stream takes place in accordance with the laws of transportation.

If the stream were uniform in velocity throughout there would be no deposition; but,

When any part of a loaded *current is checked*, deposition takes place.

In winding streams silts deposit on the insides of curves.

Why ox-bows are silted up next to the main stream and then cut off and left as crescent-shaped lakes.

Eddies silt up when the current is slack, but keep clear when the current is strong, so that there is alternate removal and deposition at any single place.

Some Important Instances of Stream Deposition.

1. *Deposition over flood-plains.*‡

3. *Formation of deltas.*
   (See under Lakes.)
4. *Formation of bars* at mouths of streams and estuaries.
   Two sets of bars in streams flowing into the ocean.
   One at the contact of stream current with quiet ocean waters.
   Another at the contact of the stream with the high-tide limit.
      Shifting of bars due to—
         a. Varying discharge of the stream.
         b. Storms and waves at sea.
         c. Any variation of the currents.
5. *Spits formed in streams.**

Deposition by overloaded streams.

An overloaded stream is one that *receives more silt than it can carry*, and hence cannot keep its channel open.

In a sense, parts of every stream are overloaded where they deposit. Such channels are kept open by freshets, or by some increase of volume and current.

Overloaded streams cut no channels, but fill them up; they are constantly damming up their own courses and seeking new channels. This leads to the spreading out of their materials as a broad, flat bed.

Illustrations: Southern California, where streams emerge from torrents of mountains on the plains; currents strong in the mountains, but are overloaded *for the lower grade* of the plains where they deposit. McGee calls this "sheet-flood erosion."† It is rather a mode of deposition by overloaded streams.

III. Mechanical Aqueous Agencies in Lakes.

At Interlaken, Switzerland, a delta formed by silt-laden lateral streams has cut the lake in two.

A delta deposited at the mouth of the Colorado river has cut off the northern end of the Gulf of California, and this northern end has evaporated.

The extension of deltas into lakes turns them into marshes, and eventually into dry land.

Many of the marshes and meadows of the Sierras are silted-up lakes. Such are the American Valley, at Quincy; Sierra Valley, and many other flat-bottomed valleys.

Salt-water lakes.

Salt lakes behave like other bodies of salt water, except that they are tideless, and consequently produce less erosion.

The amount of cutting on shores depends on the *width of the play* of the eroding agent; hence there is less on lakes than on open seas.

Salt lakes have no outlets; they lose water by evaporation.

Changes of level recorded by the old shore lines and deltas about Salt Lake.*

Present Salt Lake area, 2,170 square miles; depth, 49 feet. Former area (Lake Bonneville), 19,570 square miles; depth, 1,050 feet.

Area of Lake Erie, 9,900 square miles; depth, 210 feet.

IV. Mechanical Aqueous Agencies in Seas and Oceans.

Depth.

The oceans are deeper than the average height of mountains.

The Atlantic is from 12,000 to 20,000 feet; the Pacific's deepest is 27,930 feet.

Mt. Whitney, Cal., 14,898 feet; Illimani, 22,200 feet; Orizaba, Mexico, 18,314 feet; Aconcagua, Argentina, 23,080 feet; Mt. St. Elias

Jacent . . . . . uerbum.

Currents.*

The ocean's waters are everywhere in motion.

The currents flow in definite channels. Four miles an hour off the northwest coast of Cuba.

Theory of the causes of the ocean's currents.†

Combination of—

1. Rotation of the earth and lagging waters.
2. Trade winds, that also lag.
3. Unequal temperature of the water, producing convection.

Salinity has been appealed to, but though evaporation increases salinity, and hence density, this occurs mostly in warm regions, and is compensated by temperature. Also, there is a marked increase of salinity only in a few enclosed places, like the Mediterranean and Red seas.

Effects of ocean currents.

Effect on the distribution of life.‡

Effect on climates.

Isotherms carried north and south on the surface.

The Gulf Stream carries half as much heat from the tropics as the artics get from the sun.

The Gulf Stream carries more water than all the rivers of the earth.§

Effect on the North Atlantic and Northwestern Europe.‖

Effect on rocks formed by corals and other warm-water life-forms.

The Tides.¶

Tides are the *periodical fluctuations* of the water-level in seas and oceans.

Very small on lakes.**

(1) The cold-current system of the Pacific, and source of the Pacific coast current. By S.E. Bishop, Science, N.S. Vol. XX, pp. 338-340

Puget Sound, 20 feet; at Chepstow, near Bristol, England, 53 feet; Bay of Fundy, 70 feet.*

Importance of height due to the greater range of wave action.

Power. Tides have no erosive power except in shallow water.

They keep narrow channels open,† and increase the vertical range of the work of waves.

Mechanical Work Done by Seas and Oceans.‡

Destructive work or erosion. *The destructive work* (*i. e.*, erosion) is done by waves and tides.

Kinds of waves.

1. Ordinary, or storm waves.
2. Extraordinary, or "tidal waves."
   - *a.* Bore, or pororóca, true tidal waves, produced by submarine topography.
   - *b.* Extraordinary waves (improperly called "tidal"), produced by earthquakes or other submarine disturbances.

I. *The destructive work of ordinary storm waves.*§

On the Bahama Islands blocks of 300 cubic feet thrown 125 feet on shore, and 25 feet above high water.‖

Work confined to from 50 feet below to 100 to 200 feet above tide, or as high as undermining may affect the shore.

1. *Work below tide.*

Violently destructive 50 feet below tide, scattering stones and hauling out by undertow.*

Dana thinks but little breaking is done below the depth bared for the plunge, and that a depth of 20 feet is rarely exceeded. "Displacement at 240 feet is only a few inches." †

Scott thinks it ceases to be effective "not far below low-tide mark."‡

Agitation during storms to 1800 feet.§

Air caught under ledges and forced out through blow-holes.

2. *Work at and above tide.*

a. *Alternate compression and expansion* of air in crevices tend to loosen rock fragments, even though not reached by the water.

b. *Impact of the water* thrown against the shore.

c. *Shingle dashed* against rocks does much cutting. Blocks weighing from two to five tons hurled against the banks; all exposed shores undercut.

d. *Shingle rolled* up and down the shore.

The grinding sound to be heard upon a beach covered with loose stones.

Milky color of water due to wear.

e. *Spray* washes mechanically, and dissolves chemically,* some rocks.

Thrown over island at Rio de Janeiro; in the north of Scotland lighthouse windows broken at 300 feet.

The jagged surfaces sometimes produced by the solution of the shore rocks by spray.

f. Hydrostatic pressure of water in crevices at heights of 50 to 300 feet.

II. *The destructive work of tidal waves.*

1. The *bore*, at the mouth of the Amazon, and of the Ganges.

Its destruction of banks, forests, islands.

Produced by topography of the bottom over which a tide wave trips up.†

2. *Extraordinary waves* (improperly called tidal waves). Produced by earthquakes or other submarine disturbances.

Ships left aground at St. Croix in 1867.‡

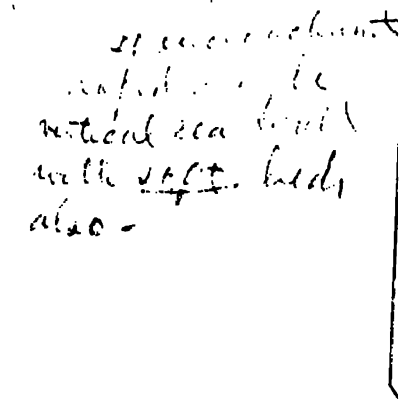
Destruction by waves during the Lisbon earthquake.

June 15, 1896, on the coast of Japan, 175 miles of coast was struck by a wave 10 to 30 feet high; some say 80 to 100 feet. It killed 26,975 persons; wounded 5,390 others; wrecked 9,313 houses, 300 larger and 10,000 smaller boats, and destroyed $3,000,000 worth of property. Land washed off, rocks broken, shore lines

see p (5)

General results of wave erosion : advance of sea upon the land - Eg. Mid. Wales - as only remnant of much of the Lowlands.

Sea cliffs - how formed -



2. The exposure of the coast, as at Santa Cruz.
3. Position of the bedding planes of rocks, or structure of the shore.
4. Character of the rocks.
   Shown by variations in the same beds at Santa Cruz.
5. Depth of the water off shore.
   Deep oceans have big waves which *break on shore;* shallows cause them to break and form surf outside before they reach the land.

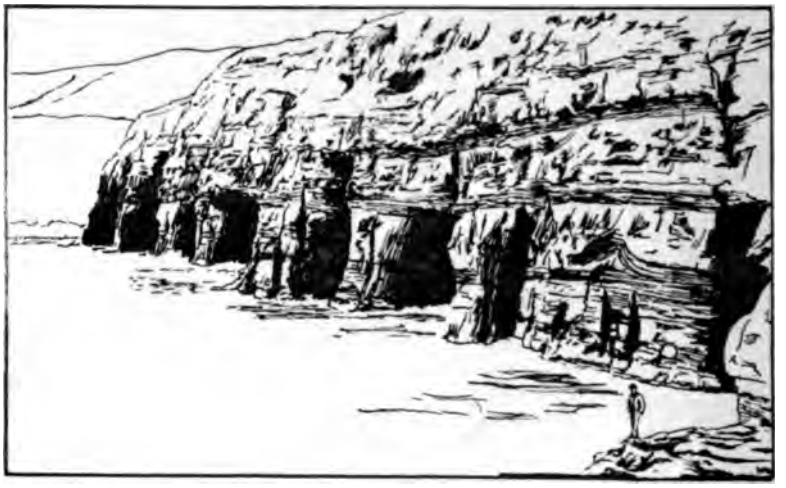
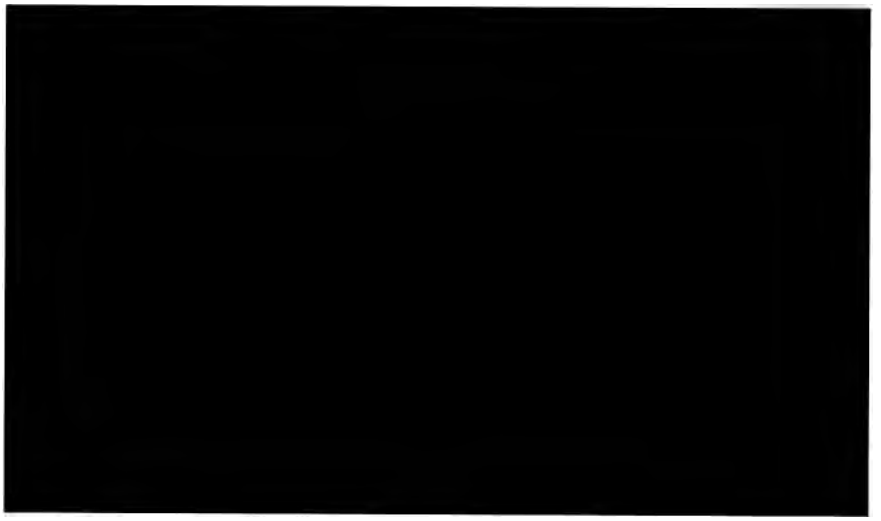
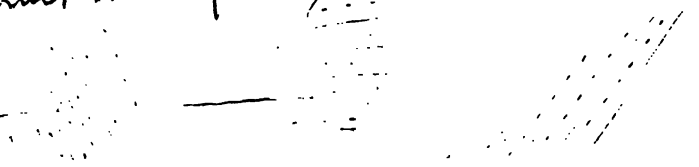


Fig. 16.—The sea-caves of the La Jolla near San Diego, California.



average wave pressure on coasts of Scotland
during 5 summer months = 611 lbs. per sq ft
average during winter months = 2086 lbs. " "
in storms many tons per sq ft.

e.g.:



Stone pillar standing with chimney near
left - also natural bridges - pinnacles - projecting
rocks mentioned in Chapter 15 - cf. fig 17 -
sea caves - cf. fig 15,

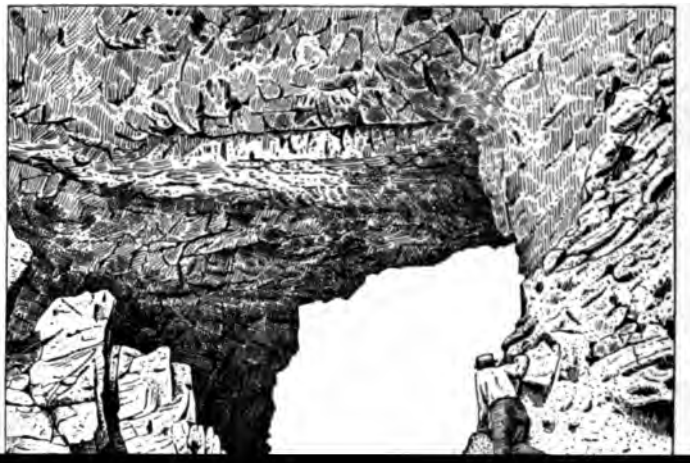
Shore forms produced by wave action.

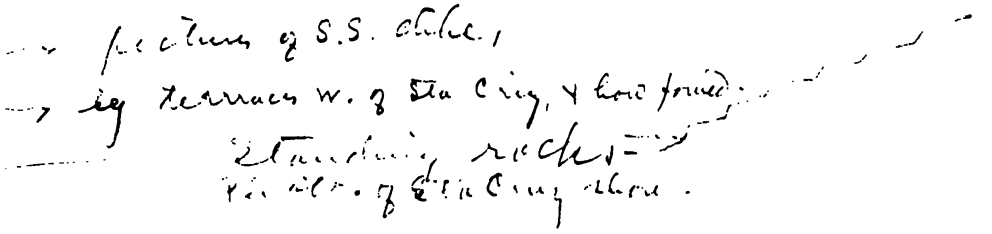
Like destructiveness of the waves, the forms produced on shores depend more or less upon—

a. The direction and force of the waves.

b. The nature and structure of the rocks.

1. Often there is a notch cut at the line of greatest activity.*
2. Shelves or terraces are sometimes cut at high and at low tide. This can only occur when the nature of the rock favors it.
3. Caves and natural arches are cut where the variation in the resistance of the rocks and the structure favors them. Portao, Fernando de Noronha.





4. The forms are sometimes the results of protective agents on the rocks, such as seaweeds, millipores, corallines, polyps, mollusks.*

Passing of land through beach condition.

General results of destructive wave work. (See p. 60.)

Constructive Mechanical Work of Seas and Oceans, or Marine Transportation and Deposition.

In general, transportation and deposition take place in seas and oceans in obedience to the laws of transportation; that is, the *transporting power varies with the sixth power of the velocity.*

Transportation in the ocean is done by—

1. Tidal currents.
2. Waves.
3. Undertow.
4. Ocean currents.

I. *Tidal currents* keep inlets open by the sweep, or ebb and flow, of the tides.†

II. *Waves carry* beach materials where they strike the beach at an angle.

They are most important where the wind blows regularly in one direction.

Sands and gravels are carried long distances. (See this Syllabus, under head of Spits.)

III. *The undertow* is the return oceanward of waters dashed on shore as waves; it is below the surface.

It is always equal to the influx of waters on the surface as waves or surf.

It hauls shore-made silts seaward.‡

IV. Ocean currents are usually so far from the land that they carry but

While sometimes the destructive power of waves is overcome by deposition of material brot down by land streams, causing the land to encroach upon the sea, this can be only temporary, and, (unless upheavals occur) the sea is sure to finally encroach upon the land, - i.e., the general result of wave action is the eating away of the land and the encroachment of the sea upon it.

Examples - British Isles once two or three times as big as now - have been worn away, principally from west.

Eg. also Island of Heligoland (near mouth of Germany) is about 3 miles in circumference, in 1300 A.D. it was 45 miles around.

Forms and Origins of Mechanical Marine Sedimentary Deposits.

Mechanical marine sediments, when deposited, take on the following forms:

1. Beaches.
2. Spits.
3. Bars.
4. Sand-barrier islands.
5. Submarine banks.
6. Deltas.

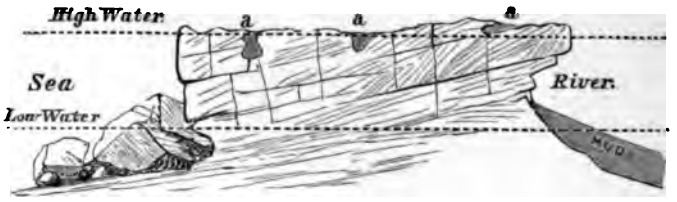


Fig. 19. - A section across a stone reef or hardened beach, coast of Brazil. (Hartt.)

I. *Beaches* are of two kinds: *ordinary beaches* and *storm beaches*.

1. *Ordinary beaches* are of sand, or other loose materials, derived from the land.

Some materials are thrown up by the waves; some are drawn seaward by the undertow.

Sands and silts swept into coves and bays, accumulate and fill out the land.

Dunes often originate on sandy shores.

Beds on beaches slope seaward.

Sometimes hardened by carbonate of lime.

2. *Storm beaches* are those thrown up by storm waves, and beyond the reach of ordinary waves.

"Sir John Coode has stated as the result of his experience that a heavy gale of wind of twenty-four hours duration would bring about far greater changes in the conditions of sand-banks and foreshores than ordinary weather in twenty-four months."*

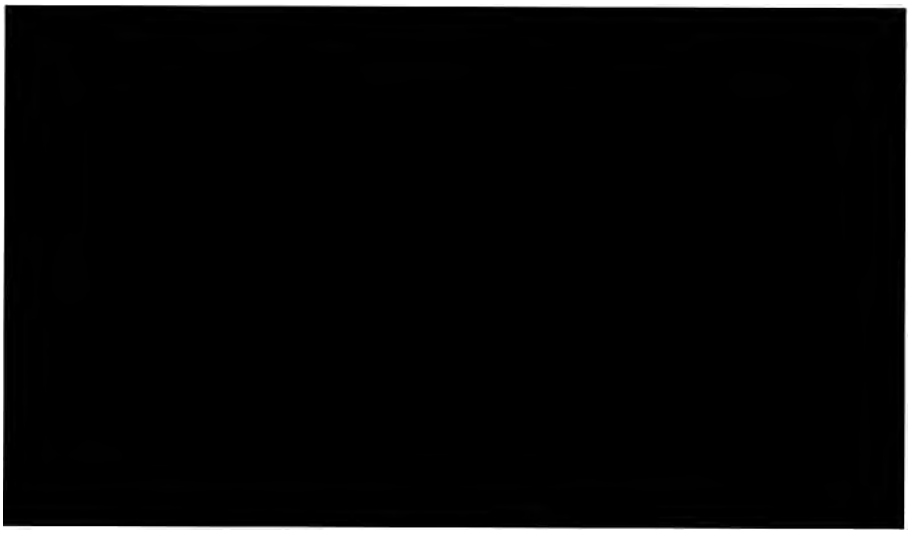
They often dam rivers and form fresh-water or brackish lakes at their mouths.

Examples:

Oceanside marshes, California.

Lake Merced, near San Francisco.

Lakes on the Brazilian coast.



The form, or line, of the beach is determined partly—

By wind and waves.

Beach cusps, their forms and origin.*

By ocean currents.

Cuspate beaches of North Carolina and South Carolina.†

II. *Spits.*‡

Spits are lengthwise extensions of beaches into the water.

Spits are formed—

1. By waves sweeping shingle and silts into quiet waters at the turn of the shore.§

Examples: Cape Cod; Dutch Harbor spit, Anamak Island, Alaska.

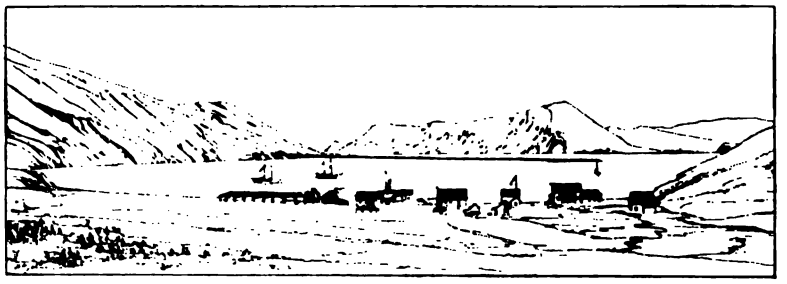


Fig. 23.—Dutch Harbor, Anamak Island, Alaska, protected by a long natural spit.

2. By conflict between waves and stream currents.

These cross the mouths of streams.

Vistula, Baltic Sea.

IV. *Barrier beaches.*

Long, narrow, and parallel with the coast.

These merge into spits and bars.

Formed by heavy waves hurling back land silts along shallow shores.*

Eventually form islands.

Examples: Texas, Mexico, Yucatan, North Carolina, Baltic Sea, Adriatic Sea.

Behind these barriers the land gains on the sea by the silting up of the lagoons.

Examples: Pamlico and Albemarle sounds and the New Jersey coast.

V. *Submarine banks.*

Formed wherever silts settle in the ocean for a long time.

Example: off Golden Gate are the Sacramento Valley sediments.

Distinguish between a submarine bank and a wave-cut shelf.

When submarine banks come near the surface the waves pile the materials above the water, and land begins.

VI. *Deltas.*

Deltas built in seas are formed in the same general way as those in lakes.

Sediments are brought from the land by streams.

Deltas at the mouths of some streams, not of others.

Probable determining causes:

1. *Character of the water* of the stream.

   Clear streams can have no deltas.

   Example: St. Lawrence river.

2. *Presence or absence of marine currents* on the coast, whether ocean or tidal currents.†

   At the mouth of the Mississippi the tide is 15 inches, and there

Plate V. — Looking southwest from Cape Santo Agostinho on the coast of Brazil. The long straight line is a stone reef or consolidated barrier beach.

Plate VI. — The great stone reef or consolidated barrier beach south of Cape Santo Agostinho, Brazil (1899).

Building of marine deltas.

Reason of certain forms in Mississippi delta. They are the continuation of the natural levees. As the silts push seaward in deeper water, the checking of the current is at the sides and bottom, so that the bottom fills below, the sides build up at the sides, but the top silts are swept into the deeper water.

*Influence of salt water on silts.**

Flocculation.

Produced by salt, alum, acids, alkalis, cold, heat.

Acids are more active than alkalis. (Joly, 330.)

Alum used to flocculate city water-supply before filtering.

Why waters containing much lime are clear.

The influence of flocculating substances upon the deposition of sediments brought down by streams.

Flocculation hastens sinking of fine silts; sediments sink in one-fifteenth of the time required in fresh water, though they lose one-fortieth of their weight.

Rate of delta growth.

Varies with conditions.

That of the Mississippi, one mile in sixteen years.

That of the Po, twenty miles since the time of Augustus.

Bay of San Francisco filling about the ends.

The origin of Salton Lake, California.

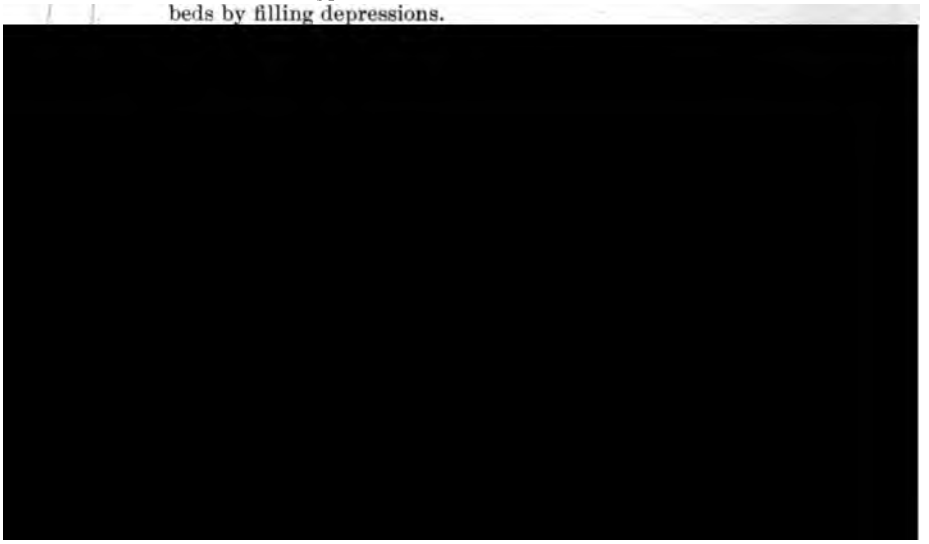
Delta on a rising shore.

Example: at Palo Alto, California.

Position of marine sediments.

Beach deposits *slope gently seaward.*

Most deposits are *approximately horizontal*, and tend to flatten their beds by filling depressions.



Delta on rising shore - eg - San Francisquito cr. N.E. of Palo Alto -

without flocculation the water of the sea would be muddy

Sea Level -

General Considerations Concerning Mechanical Sediments.

1. The sediments of streams are only the decayed and broken rocks of the land.
2. The ocean's bottom is the destiny of all the land.
3. The rate of removal depends on —
   a. Topography. (The steeper slopes go faster.)
      This is true both of stream erosion and wave erosion, for—
         (1) Velocity is greater, hence transporting power is greater on the steeper land-slopes.
         (2) On steep coasts the waves reach the shore with greater force, and the undermining is more effective on account of the greater masses undercut.
            On coasts having low grades the off-shore shallows break the force of the waves before they reach the beach.
   b. Climate.
      Freezing and thawing hasten removal.
   c. Structure and character of the rocks.
4. Most removal (erosion, or denudation) is done during storms, or in times of freshets, owing to the increased volume and velocity of streams, and to additions from temporary side streams.
5. Erosion stops at, or not far below, the surface of the ocean.
6. Hence eroded surfaces tell of a land condition.
7. The hardening of a rock is, in a sense, an accident.
8. The laws of transportation and deposition by water determine the disposition of the load of a current.
9. Thus coarse sediments can be moved only by strong currents, and fine ones can be laid down only in weak currents.
10. The nature of the sediments thus reveals the nature of the currents

V. Ice as a Geologic Agent.

The geologic work of ice is done—

1. In the mechanical expansion on freezing, whereby rocks are chipped off and disintegrated, and earth-slopes altered. (Discussed on p. 24.)
2. By glaciers or ice streams.
3. By icebergs and floe-ice.

GLACIERS.*

Outline of glaciers and their work.

Moisture precipitated where the temperature is below freezing, ***falls as snow.***

Snow packs as ice, and flows as ***streams of ice.***

These streams are called ***glaciers.*** (See Plate VII.)

They obey ***the law of flowing streams*** in general, so far as movements are concerned, though they move very slowly.

Debris falling on the side of a glacier is carried down on top, or sinks into the body of the ice.

Flowing down to warmer regions the ice melts, and when it melts more rapidly than it is replaced by snow, the glacier ends and the debris makes a moraine or heap, while the ice, turned to water, flows away heavily charged with mud.

Origin of glaciers.

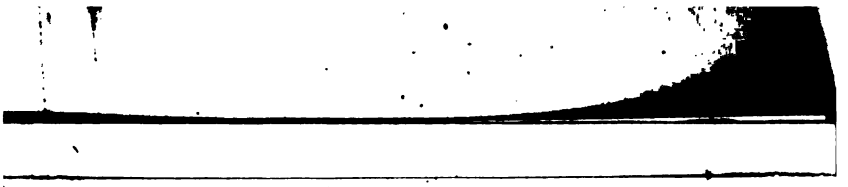
All glaciers originate above the line of perpetual snow. The line of perpetual snow at sea-level is about the poles; in passing from the poles toward the equator it rises higher and higher above sea-level.

"continental"

Kinds of glac's – ice caps (Greenland) valley glaciers, alpine glac's, ... glaciers

Piedmont glacier (depositing ends mtls)

[redacted]



Juvare,

Mt. Hood, Oregon.

Sabbath. July 26th '01.

[redacted]

Plate VII. — The Fiescher glacier, in the Bernese Alps, Switzerland.

Compacting of snow to ice by warmth and pressure.
Illustrated by squeezing snow.
Blue ice in tunnels.

Hence the conditions necessary to the formation of glaciers are—

1. Region extending above the perpetual snow line.
2. Abundant precipitation.
3. Difference of temperature to hasten flow.

Movements of Glaciers.

Rate of movement.

Swiss glaciers move 150 to 400 feet per year.
Aar glacier moves 330 feet per year.
Boisson glacier moved 210 feet a year for 41 years.
Muir glacier moved 7 feet per day,* x 365 = 2,555 feet per year.
Greenland glaciers move 8 feet to 8 miles per year.
Rates vary according to—

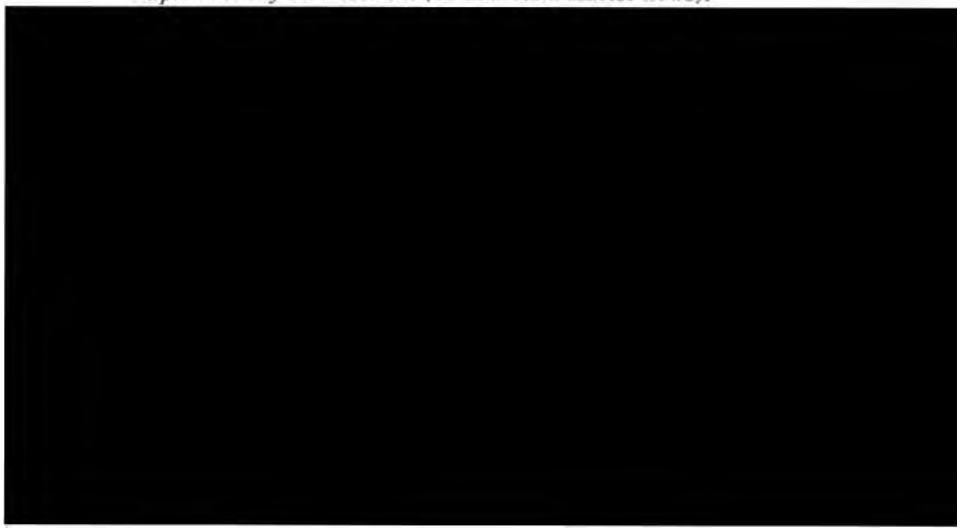
1. The slope of the bed.
2. The warmth of summer.
3. The snowfall or mass of the glacier that presses behind.

Method of determining the rate of movement.

Transit and stakes.
General law of glacial flow is the same as that of streams.†

1. Move more rapidly at top than at bottom. (Owing to fricton on bottom.)
2. Move more rapidly in middle than at sides. (Owing to friction on sides.)
3. Swing around curves with the rapid current on the outside.
4. Flow more rapidly on steep slopes. (Less friction.)

Explanation of ice movement (or how solid matter flows).



Trinidad lake.

But these substances, though brittle, stretch; ice does not stretch.

5. *Regelation* or *refreezing* theory of Tyndall.

Process shown by pressure into various forms, by cutting with wire, by the refreezing of the small broken fragments.

Glaciers are like ice fragments in a mold.

The pressure is all produced by gravity.

Hence large glaciers flow faster than smaller ones on the same slope.

Glaciers are not smooth and clean, but irregular and dirty.

Irregularities made by crevasses.

Crevasses.

Crevasses are cracks in the glacier.

Produced by tension.

1. Where the ice increases its slope or flows over a ridge.

These ridges may either cross, or be parallel with, the glacier.

2. Where there is a different rate of movement of one part over another.

Producing—

a. Transverse lateral crevasses.

Transverse lateral crevasses point diagonally up-stream.

Why they point up-stream and not down.

How they swing down-stream and are crossed by new ones.

b. Transverse vertical crevasses.

Transverse vertical crevasses within the ice point up-stream from the bottom, but their tops swing gradually down stream.

Principle the same as for transverse lateral crevasses.

3. Where the ice stream widens, as sometimes happens, at the end

Terminal moraines are the accumulations of debris at the ends of the glaciers.
They are made of the lateral and medial moraines, and of all the solid matter carried in the body of the ice.

Forms of terminal moraines determined by the form of the end of the glacier.
Circular when the glacier is lobate.
Not water-sorted, but a heterogeneous mixture of unsorted material.

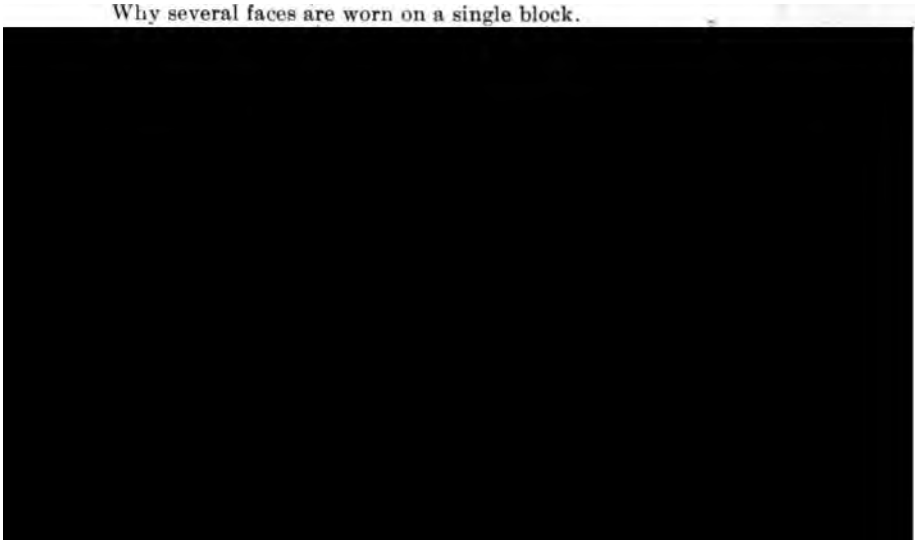
Ground moraine is the debris, soil, clay, etc., on which the ice sometimes rests.
Glacier often slides over the moraine, and over part of its own mass, at the end.*

Erratics or Glacial Boulders.

Blocks of rock carried by ice, and left scattered by the melting of the ice.
Erratics often occur in large numbers.
Sometimes they are of very large size.
In Switzerland, 40 to 73 feet long by 20 feet high.
One of 240,000 cubic feet is biggest.
The Madison, N. H., boulder, 70,000 cubic feet.†

Striæ.‡

Striæ are scratches made *on the bed-rock* over which ice moves, or *on the blocks held in the ice.* (See Plate VIII, opp. p. 94.)
Rock fragments held in the grip of the ice and pushed forward scratch the bed-rock.
The striæ cut deep at one end show the direction of the movement of glaciers.
Fragments held in the ice, ground against the bottom, are *striated* and *faceted.*
Why several faces are worn on a single block.



1. [illegible]
2. [illegible]
3. [illegible]

3. Turning of stones.
4. Bringing of glacier under local topographic influence.

Difference between *water-wearing* and *ice-wearing* of rock in place.*

Glacial Streams.

Superglacial streams.

Formed by the melting of the ice.

Plunge into crevasses, forming *moulins*, and grinding out pot-holes.

Lucerne glacier garden.

Archbald pot-hole.†

Subglacial streams are the superglacial streams after passing beneath the ice through crevasses.

Wind and cut narrow, deep channels in the bed-rock.

Channels exposed at Grindelwald and Zermatt, Switzerland.

On large glaciers they sometimes come to the surface again.‡

Geologic Work of Glaciers.

Geologic work of glaciers is done as erosion, transportation, and deposition.

I. *Erosion.*§ Rock-set ice grinds its bed; grooves, striæ, polish.

Streams cut pot-holes, wear channels.

Color and character of water; *gletscher-milch.*

Amount of wear shown approximately—

1. By topography.
2. By gletscher-milch examination.
3. By glacial debris, or drift, left over the country on the retreat of the ice.

II. *Transportation.* The materials carried are either in the form of lateral or medial moraines, materials scattered through the ice, or silts washed along by glacial streams.

Conditions influencing rate of erosion –

(a) Rate of movement

(b) Amt. & character of material carried at bottom

Too much material = slow movement –

" little " = little wear –

over loaded bottom; pebbles may slip over it & not wear bed rock at all –

(c) Character of bottom rocks –

soft = much erosion

Hard = little "

glaciers & their work – eg – [illegible]

of Alb. Sa. Ind, Ohio & [illegible]

Epoch. (dependent upon glacier)

Effect of glaciation on the topography.

Effects of erosion on hills.

Roches moutonnées.

Exceptional cases of angular rock fronts facing the ice currents; caused by the ice packing against them, and thus preventing erosion.

Clearing off of soil.

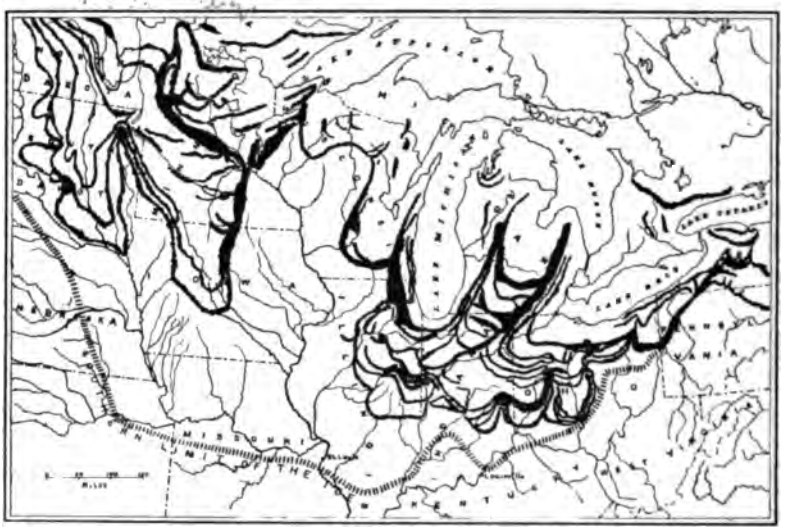
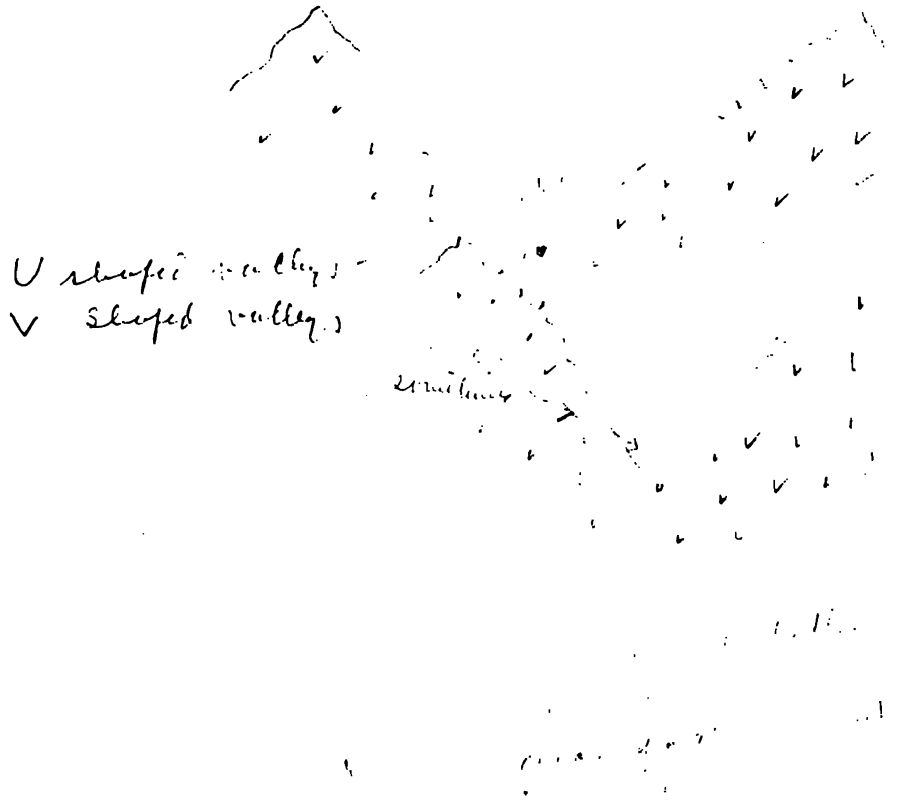


Fig. 24.—Map showing the lobate forms of the principal moraines of the Mississippi Valley region.


U shaped valley
V Shaped valley

[redacted]

2. Striæ and drift below the present ends of glaciers.
3. Trees, that were cut off by ice, below present glaciers.*
4. Difference in vegetation on old and newly glaciated surfaces.†

Swiss glaciers reached a maximum about 1820; retreated till 1840; advanced till 1850–60. Reports from glaciers in all parts of the world showed many of them retreating in 1899; a few were advancing.‡

Evidence of the unquestionable origin of glacial phenomena.

Striæ on bed-rock.
Striæ on boulders.
Old moraines; forms; mixing of material not water-sorted.
Transported blocks.

Pleistocene or Ancient Glaciation.

These phenomena led to the discovery of the former glaciation of Switzerland:

1. Striæ down the valleys. (See Plate VIII.)
2. Erratic blocks from the Alps on the sides of the Jura mountains.

Time required to carry blocks suggests the length of the glacial epoch: 1,000 to 2,000 years, as glaciers now move. Probably moved faster. The ice rose 4,400 feet on the Jura mountains, and flowed to Lyons, France, a distance of more than 200 miles. Another branch flowed eastward toward Zurich about 200 miles.§

Reluctance with which theory of glacial epoch was accepted.

Extension by Agassiz of the theory to England, Scotland, and Ireland. Shown by topography, drift, and striæ.
Extension to America.
Confirmed by Agassiz landing at Halifax, N. S., in 1846.‖

Glaciation in North America.

Plate VIII. — Striated sandstone exposed in the Glacier Garden at Lucerne, Switzerland.

Origin of the ice.

The ice did not come from the north pole, but from three principal centers of accumulation.

The ice moved southwest up the St. Lawrence valley.

Local origin of the ice in the Rocky mountains, Sierras, etc.

Lecture Notes accompanying Lecture illust. Slides.

GEOLOGICAL AGENTS.

Mechanical.-

Atmospheric { Direct / Indirect

Aqueous.

Chemical.

Igneous.

Organic.

DIRECT WORK.

(The wind, carrying, tearing, depositing

Carrying.- dust, sand &c. Transport

(1) Wearing by Wind.-

a. Wind blast on rocks, Sand Normal.

b. Wind weathered rock &c.

(2) Wind deposits (Strata)

a. Ripples in sand.

b. " " "

c. Sand drifts, Lake Michigan.

d. Sand dunes over forest, Pine Plains.

e. Sand dunes " " "

(2a) Wind deposits. (Structure)

3. Wearing of hills on ice-ward side.
4. Distribution of material.
   Granites in Indiana and Illinois.
   Copper from Lake Superior.*
5. Effect on drainage.
   Streams that flowed toward the ice source were dammed up and left terraces around the ancient lake margins.
   Some stream channels were entirely obliterated as surface features.

Lobate forms of the ice shown by —

1. Forms of terminal moraines and interlobate moraines.
2. Direction of striæ.

Thickness of the ice.

In the eastern United States the thickness is shown on the mountains.
Elk Mountain, northeastern Pennsylvania, glaciated 2,700 feet a. t., and 1,500 feet above the valley.†
Mt. Washington 6,000 feet a. t., boulders on top.
Ice thinned as the epoch waned, and finally came under the influence of local topography.
Cross striæ (see p. 88).

Retreat of the ice.

Concentric parallel moraines.‡

Evidence that the country was formerly higher to the north.

1. The fjord-like bays of Maine.§
2. Hudson river gorge out at sea could only be made by subaerial erosion.‖
3. Preglacial channels of Cuyahoga at Cleveland, Ohio.
   Wells strike bed-rock at 228, 333, 470, 203, 392 feet below Lake Erie water-level (see p. 102).
   These must have been made before the glacial epoch, for they are

Some of the results of glaciation in North America.

The region affected varies between —

1. The narrow valleys of New England, New York, and Pennsylvania.
2. The broad, flat plains east of the Rocky Mountains.
3. The basin regions of the Great Lakes, now reaching (Huron) 121 to 492 feet (Ontario) below ocean level.
4. The far inland Rocky Mountain ranges.
5. The Pacific ranges of the Cascades* and Sierras.†

It is to be expected that in so varied a region the influences would vary.

[redacted]

I. *Influence on vegetation.**

Cold climate crowded vegetation southward. Retreating ice left behind arctic forms.

Arctic forms left on mountain tops.

Cases of Mt. Washington, Teneriffe, and Java.

Swiss mountains have many forms that could only have come from the north when it was cold in the valleys.†

II. *Influence on faunas.*

Insects left on Mt. Washington.‡

They cannot live in the valleys now.

Fresh-water fishes and mollusks migrated northward from the Mississippi drainage,◊ and passed over the present divides when the drainage flowed into the Mississippi.

III. *Influence on topography and drainage.*

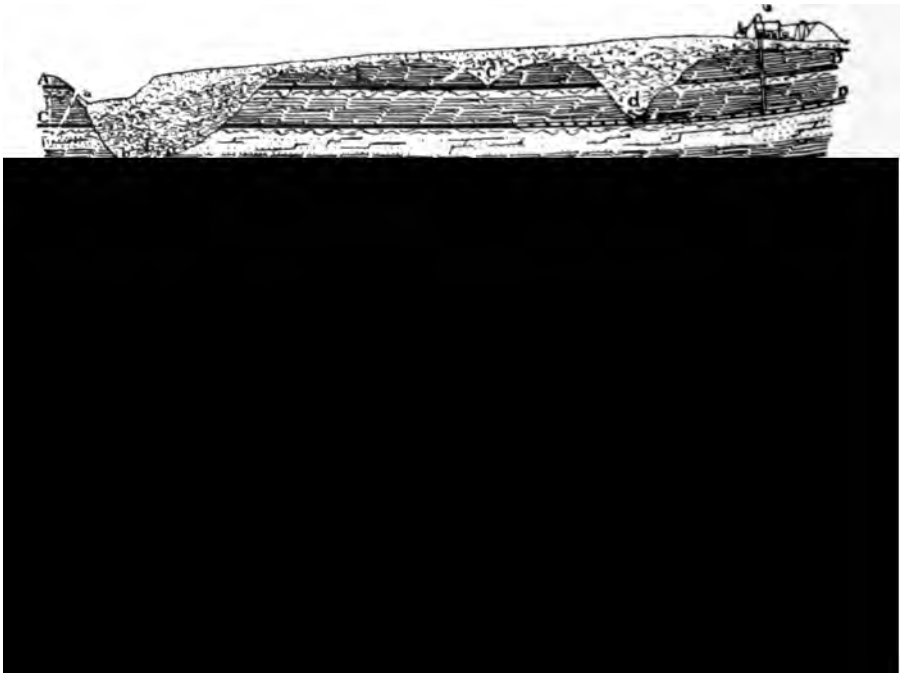
Moraines. Long Island, N. Y., largely a terminal moraine resting on Cretaceous rocks.‖

Kettle-holes and lakes in the moraines.

During the ice age former streams were buried and their channels filled with drift after the retreat; new channels had to be established:¶ Cuyahoga (see p. 98), Chicago,** Niagara.

New drainage developed as the ice melted.

Lake Michigan drained southward; buried channels;†† impossibility of locating many of them.



Mohawk–Hudson drainage.

Terraces. Origin of Niagara gorge. St. Lawrence drainage last.*

Lake Agassiz.†

Ponding back of the water by the ice.

Winnipeg on the old lake bed.

Postglacial lakes.‡

Origin of glacial lakes.

Left by morainal dams.

Left in scooped-out rock basins.

"Finger Lakes," of New York.

The former northward drainage dammed by drift.§

Glacial lakes of the Sierras.

Donner Lake.

Fallen Leaf Lake.

IV. *Influence of glaciation on agriculture.*

Nature of glacial soils: *mixed*, *pulverized*, hence more fertile and more valuable.

In Ohio the glacial border separates the less productive from the more productive parts.

Drift soils of the Northwest noted for fertility.‖

In the driftless area of Wisconsin the land is worth $10 an acre, or less.

Loess of the Mississippi valley.

Origin from flooded streams?¶

At Louisville, Ky.; St. Louis, Mo.; Omaha, Neb.; Kansas City, Mo.; Des Moines, Iowa; Vicksburg, Miss.; Memphis, Tenn.

Fine soil.

V. *Influence on roads.*

Glacial gravels make good roads.

Roads as an index of civilization.

Other Theories Advanced to Explain Glacial Phenomena.

(These are mentioned as illustrating the process by which a natural explanation is sought for natural phenomena.)

1. *The deluge* of biblical account.*
2. *Tipping up* of the north end of America, and the elevation of the Alps.†
3. *Waves of folding rocks.*‡
4. *Iceberg theory.*§
5. *Destroyed planet and the tail of a comet.*‖

Objections Formerly Urged to the Glacial Theory.

I. *The striæ show that the ice moved up-hill.*
   Some up-hill movements are local.
   In the St. Lawrence valley the slope has changed since the glacial epoch.

II. *Present climate* would be colder.
   But 5° to 6° lower temperature would bring the Swiss glaciers to Geneva; hence a very slight change of the annual temperature would cause a glacial epoch.

III. *Agassiz's theory of South American glaciation.*
   This theory was that a glacier formerly flowed down the Amazon valley.¶
   This proved too much; life would have been extinct.
   This theory not found correct.**

Date of the Glacial Epoch.

Can be shown by the geologic work done since glaciation.

Review of subject of glaciers -
Illustrated by lantern slides. Nov-7

1 Origin
2 Kinds -
a Ice caps & Continental glaciers -
b Piedmont types -
c Cliff [illegible] -
3 Movement, Also - advance and retreat
4 Structure -
5 Topography of ice surface
I Crevasses -
(a) Transverse
(b) Longitudinal
II Seracs -
III Pinnacles - stone coffee -
IV Dirt wells.
V Ridges by moraine protection at sides
6 Moraines -
a Lateral
b Medial
c Terminal -
7 Glacial Ground -
8 Striae - Glacial erosion
9 Transportation by ice
10 Character of glacial debris & deposits.
11 Topography formed by glaciation
12 Hanging valleys -
13 Glacial Lakes -
14 Causes of glacial period
15 Icebergs

[redacted]

Length of the Glacial Epoch.*

Was man here during or before the glacial epoch?

Implements should be in the drift if he was here.

The Trenton gravels, in which human implements have been found, are far south of the ice margin.†

Minnesota.

Stump and root holes.

Burrowing of animals.

In Europe.‡

Will the Glacial Epoch Recur?

Depends on cause or causes.

If the cause recurs, the epoch will.

If the cause is astronomic, its return is to be expected.

Evidences of interglacial epoch.§

Several lignite beds in the glacial deposits near Zurich, Switzerland.

Topographic variation and difference in oxidation in Illinois, Indiana, and Yosemite Valley region.

Shells in wrinkled loess.

Nature of marine fossils interbedded with drift.‖

Evidence of previous glacial epochs.¶

In the Mesozoic rocks of India.**

In the Carboniferous rocks of India and South Africa.

In Tertiary, or pre-Tertiary, rocks in South Australia.††

Hence the glacial epoch may return.

The conditions move slowly.

Causes of a Glacial Epoch.

Leblanc thinks an average of 7 degrees Centigrade lower than now would produce glacial epoch.*

Temperature falls 1 degree Centigrade for 188 metres in elevation.

Snow line in the Alps is at 1,200 metres; a decrease of 5 degrees in the temperature of that region would bring the ice down to 260 metres, or below Geneva.

Difference of temperature may have been due to geographic or astronomic causes.

Suggested geographic causes.†

1. Change of ocean's currents.
2. Change of trade winds.
3. Elevation of land above snow line.

   The sea bottom of Norway was at least 2,600 metres higher than at present.‡

   That northern North America was higher is shown by the fjords of Maine and British Columbia and by the ice flowing up the St. Lawrence valley; Canada was at least 1,200 feet higher than at present.
4. Change in distribution of land and water.

   We have no evidence of such changes during the glacial epoch.

Supposed astronomic causes.§

5. Increase of the obliquity of the ecliptic.
6. Combined effect of precession of equinoxes and of the eccentricity of the earth's orbit.
7. Changes in position of earth's axis.

   In Tertiary times it was warmer near the north pole, as fossil plants show.
8. The turning of an exterior crust over a fixed core.‖
9. Variation of the heat radiated by the sun.

Icebergs.

Formed by sea-water lifting the ends of glaciers.
Humboldt glacier, Greenland, 60 miles across at the end.
Muir glacier, Alaska, two miles across at the end.
Bottoms set with stones and debris.
Floating, they carry away this debris for thousands of miles.
Icebergs melt and the stones they carry fall to the bottom.
Banks of Newfoundland.
Stranding of bergs in shallow water.*
Only one-eighth to one-seventh part of the ice remains out of the water.
Icebergs can ground in 2,000 feet of water.
Contorting of drift by the dragging of icebergs.
A large area south of the glaciers probably affected by bergs.

Floe-Ice.

Work of the ice in streams when the ice breaks up in the spring.
Stones and earth are carried down.
Ice piled on the spits of the Great Lakes.

* Striation by dragging bergs. Chalmers, Geol. Surv. Canada, VII, part M, 104-106. Ottawa, 1895.
Proc. Liverpool Geol. Soc., 1895, pp. 383-386.

CHEMICAL AGENCIES.

Under the head of Chemical Agencies come the decomposition and recomposition of minerals and rocks, and the formation of many of our most valuable mineral deposits.

The operations of chemical agents are, for the most part, invisible; but the results of such operations become apparent with time.

When rain falls on the earth the water does either *mechanical* or *chemical* work.

1. It flows off over the surface as freshets (doing *mechanical* and *chemical* work), and returns to the air by evaporation.
2. It soaks into the ground, to emerge as springs, or to be evaporated from the soil surface (doing *chemical* work).
3. It reaches the sea by underground channels (doing *chemical* work).

All stream, spring, and well waters contain mineral matter in solution.

This is shown by evaporation of the water.

Mineral matter is derived from the rocks passed through.

Many of these minerals are considered insoluble in water.

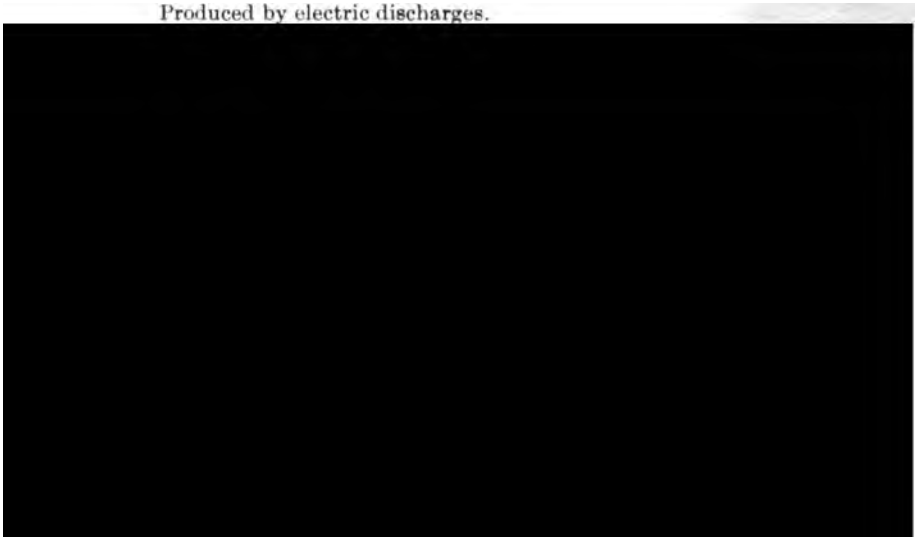
Why the minerals are in solution.

The water is not simple, pure water.

The solvent power of water is increased by—

1. *Carbonic acid* (CO_2) derived from the air.
2. *Nitric acid* derived from the air.

Produced by electric discharges.



- Mechanical
  - Atmospheric
    - Direct
    - Indirect
  - Aqueous
- Chemical
  - Solution
  - Precipitation
- Igneous
- Organic

No two streams are alike.

The same stream varies from time to time.

How the amount is determined.

Measure of discharge frequently.

Determination of matter in samples.

Examination of the Arkansas river water.

Matter in solution varies from 11 to 71 grains per U. S. gallon. Removed in solution in one day from 13,000 to 68,000 tons; in the year 1887–88 the total removed in solution was 6,828,350 tons.

*All of this is invisible.**

Minerals in solution mostly salt, gypsum, epsom salt, lime carbonate.

Difference between streams.

Due to rock differences of the hydraulic basins.

Due to the nature of the water (*i. e.*, the contained acids).

Streams from swamps and marshes usually contain much organic acid. Tropical streams often carry much organic acid on account of the rapid decay of vegetation.

Difference in the same stream due to —

Drainage coming at different times from different parts of the basin, where the rocks differ.

Drainage sometimes from underground, sometimes from surface water.

Concentration of water by evaporation in dry weather.

Effects of Chemical Erosion.

Rocks are minerals; some minerals are easily soluble, some are nearly insoluble, but all are soluble with time.

Materials removed are minerals dissolved from the rocks.

Chemical action results in the *decomposition* and *removal* of rocks.

The chemical operations of decomposition and alteration of rock† result in —

The Formation of Caves.*

Natural caverns are formed in four ways:

1. By the removal of rock in solution.
2. By the underflow of lava beneath hard crust.
3. By the mechanical action of waves on coasts.
4. By the differential weathering of cliffs.

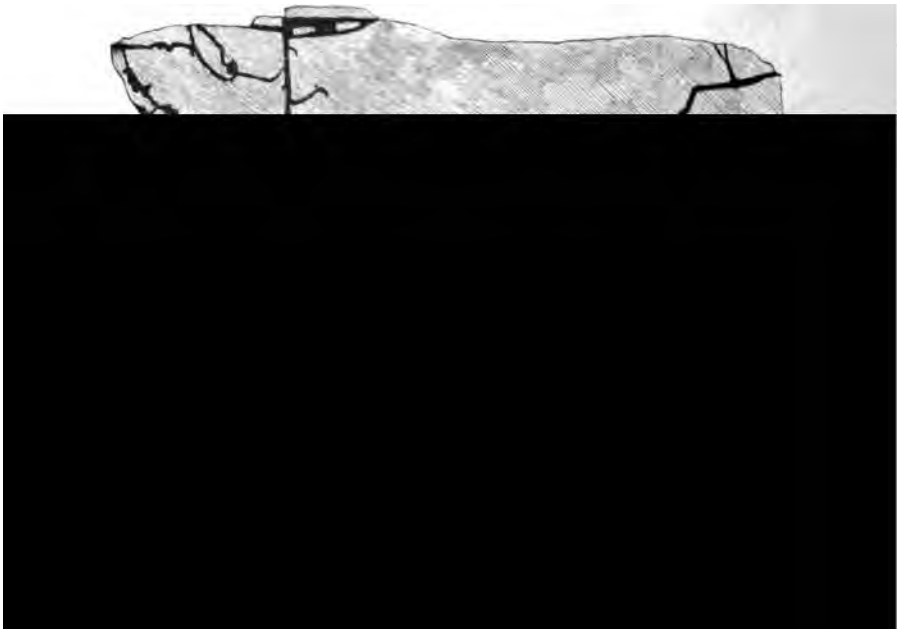
Fig. 28.—Ideal section in a limestone region, showing the relations of caves to sink-holes and natural arches. (Shaler.)

I. *Differential solution and removal* of rock, aided by mechanical wear.

Mammoth Cave, Kentucky, has 35 to 40 miles of tunnels along which one can walk, besides many miles of smaller ones along which one can creep. Cavern 70 to 200 feet high.

500 caves in Edmonson county, Ky.†

The limestone regions of Kentucky extend into Indiana, Tennessee, Arkansas, and Missouri. Wyandotte cave, Indiana;‡ Nicajack cave, Tennessee; Luray cave, Virginia.§



N THE COLOSSAL DOME

THE LARGEST SUBTERRANEAN CAVERN KNOWN

40' long, 174' high

n 5 the Colossal Cavern.

1. Book Lovers Magazine - Oct - 1904

on the part of the Mexican government, this drugging continues. In point of fact, the Indians, acquiring a diseased taste for the intoxicating drink, refuse to drink the unadulterated product.

In the large cities pulque is vended at the various pulque-shops in both copas and copitas—large glassfuls and small ones. Also, it is well advertised by traveling pulque-wagons on wooden wheels, decorated with gay flags and flowers, and sometimes led by a band of wildly-tooting musicians. As for the pulque-shops, their name is Legion; you will find one on every corner; you may even consider yourself lucky if you are not obliged to live over one! And new pulque-shops are constantly being opened, when a large and flourishing band plays loudly in front of the shop, while numerous copas are ladled out to customers and passers-by. The interior of a pulque-shop is instructive and amusing. Back of the long, low bar you will invariably find a large and ornate painting of Mexico's favorite Saint, "La Virgen de Guadalupe." Flowers, real and artificial, adorn it, and candles burn devoutly underneath. The ceiling is always embellished with highly-colored pictures of saints, cherubim and seraphim. For, with all his faults, the

yourself more than usually; your kitchen, at any hour of or night, is not the scene of induced brawl.

This is one side of the j regards pulque. The othe the owner of a big maguey pl is a very different one. He, h is to be envied; for a pulqu farm is in most cases as luc gold mine, and ten times mo

An average hacienda will date sixteen hundred plan hectare—two and a quar Each of these plants will giv dred and twenty-five to on and sixty gallons of pulque, about eight cents per gallon allowing duly for waste and it will be seen that on an unfailing crop, as maguey c being, such a hacienda will cl of five hundred dollars per ac and year out—one-tenth of t tion producing each year. of an idea as to the use of Mexico can be obtained w stated that the internal reve on the amount sold is s thousand dollars a year.

Pulque will never be an export from Mexico. For o

GHAN'S DOME FOUR HUNDRED FEET LONG, ONE HUNDRED FEET HIGH

"Colossal Cavern" a cave 1/2 mi from
ve, Ky. (from Book News Magazine - Oct '04.

nearby, leads to the Arrow Head and
Festival Hall, over Phosphate Mountain,
seventy feet high—an appropriate place
for cooling drinks—and right next to the
Dining Room. Here is a formation
which closely resembles the Full Dinner
Pail of recent political notoriety. After
having feasted in imagination, the trav-
eler could, if the preceding pathways
had permitted, take a spin in his auto
or on a bicycle. A beautifully smooth,
hard sandy road, called Bicycle Avenue,
stretches invitingly several hundred feet
from the Dining Room door. From a
nearby cliff top a miniature Niagara dives
into a huge crater, disappearing myster-
iously among the rocks, and its waters
emerging no one knows where. On the
[illegible] is one of the most perfect specimens
[illegible] of Nature's palaces [illegible]
[illegible] imitation of underground cave formation.
[illegible] And so one might roam at the
[illegible] of each of which is equal
[illegible] the [illegible]

readily weave innumerable
not only is the Colossa
largest cave in the world
ered, but it contains the
room in any known unde
This room is called the
It is sixty feet high, one
twenty feet wide, and hi
—a banqueting-hall fit f
adornment, and large e
the combined political
all the parties in the c
temperature would be
summer gatherings of
while the tedium of bu
relieved by fascinating fr
various wonders of the C

After having traverse
in his inspection of
subterranean region, the
to the world of sunshine
once more, loath to le
entertainment and feeli
heart has not been rev

INESE ROOM. Colossal caverns 1½ mi from
th Cave. (From Bookbuyers Magazine - Oct- 1904

A HINT OF THE "NEW DISCOVERY"

nearby, leads to the Arrow Head and Festival Hall, over Phosphate Mountain, seventy feet high—an appropriate place for cooling drinks—and right next to the Dining Room. Here is a formation which closely resembles the Full Dinner Pail of recent political notoriety. After

readily weave innumerable legends not only is the Colossal Caver largest cave in the world so far ered, but it contains the largest room in any known underground This room is called the Great It is sixty feet high, one hundre

NESE ROOM. Colossal cavern 1½ mi from
th Cave. (From Booklovers Magazine - Oct- 1904

Why the great caves are in limestone regions.
The processes of solution and removal.
Such caves formerly supposed to be formed only above ocean-level.
But waters from the land discharge beneath the ocean, hence there must be rock removed below sea-level.*

II. *By the underflow of lava* beneath a cooled hard crust.
Method of formation.
Such caves are formed only in volcanic regions.
The lost streams of volcanic regions in some cases flow through these caverns.
Kildá river, in Iceland, is only two miles long; the rest of it is below ground.†

III. *By the mechanical action of waves* on coast lines. Processes of the wave work.
Chemical action of sea-water often aids mechanical work.‡
Caverns made in this way seldom go far into the rocks.
Examples: at Santa Cruz, California; at Santa Cruz Island; at Fernando de Noronha. (See Figs. 15 and 16, pp. 60 and 62.)

IV. *By differential weathering* in cliffs.
Processes of weathering.
Why caves are formed in one bed and not in another.
Uses made of cliff caverns.§
(See Plate IX.)

Blowing, "Breathing," and Sucking Caves.

Movements of air due to varying temperatures inside and outside of the caverns.
In summer the inside air is cooler and descends.
In winter it is warmer and rises.

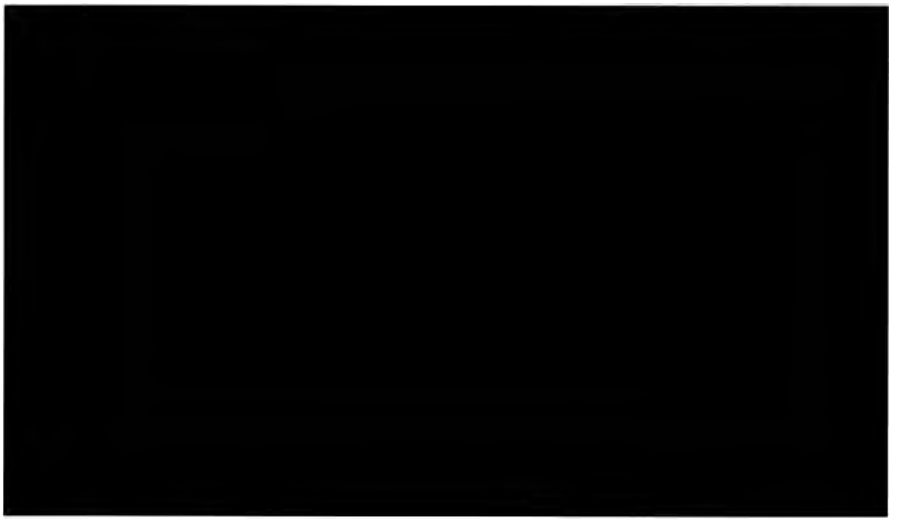


Plate IX. — Natural caverns used as houses by the "Cliff-dwellers." Walnut Cañon, near Flagstaff, Arizona.

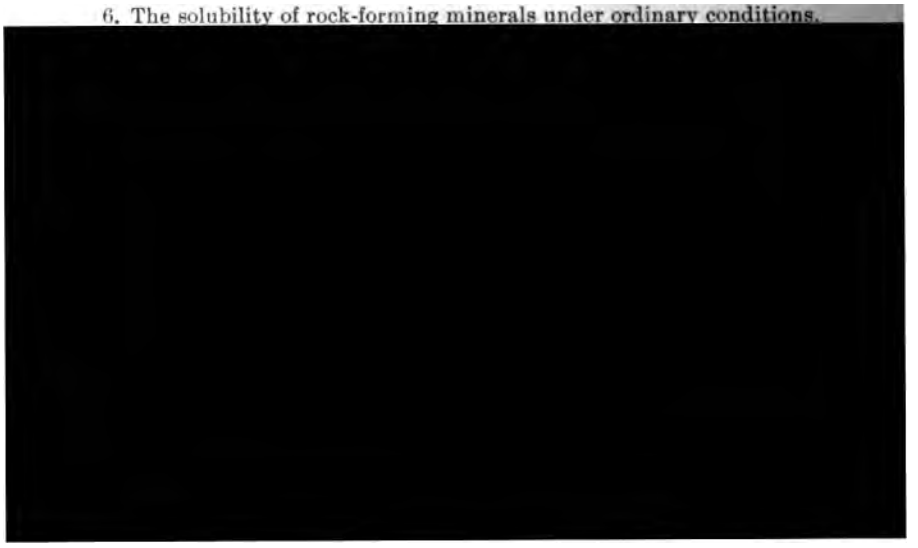
Found chiefly in limestone regions.
Due to solubility of limestone.
Examples found in the cave regions of Kentucky, Indiana, Tennessee, Virginia, Missouri, and Florida.*
Eden Valley, Ky., covers 2,000 acres;† 1,000 sink-holes in that county.
Ponds made by puddling clays in sink-holes.
Underground drainage of cave regions.
Mammoth Springs.
Why they fluctuate so little in volume.
Method of tracing streams by the use of fluorescein.

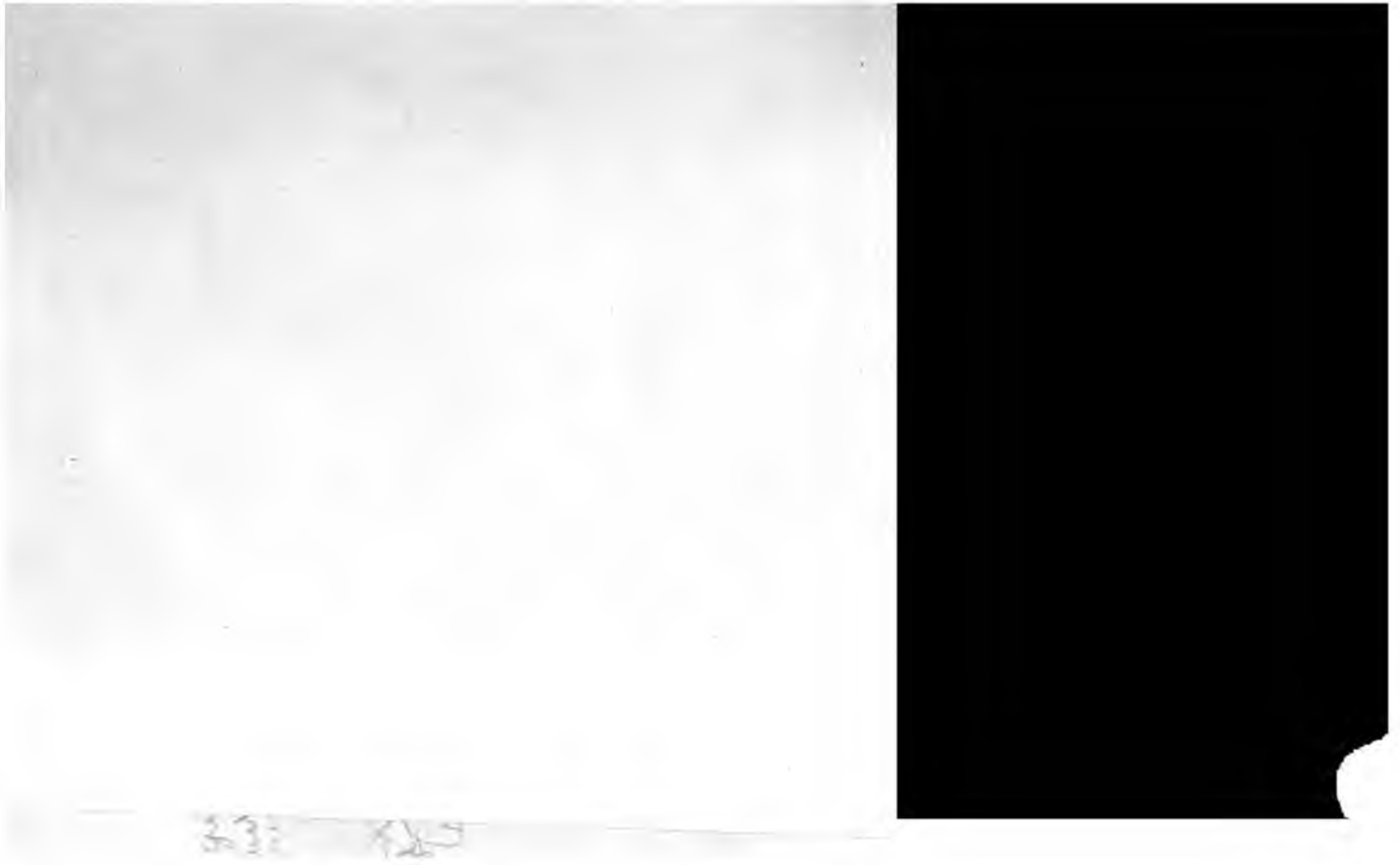
Natural Arches.

I. Formed by the destruction of caverns.
Natural Bridge of Virginia in synclinal fold.
In limestone or volcanic regions.‡ (See Fig. 28, p. 118.)
II. Formed by encroachment of sea on isthmus or peninsula.
Examples: Santa Cruz, California; Fernando de Noronha.
(See Fig. 18, p. 66.)

Chemical Deposition.

It has been shown that *solution* is due to—
1. Acids in the water (derived from various sources).
2. Pressure.
3. High temperatures.
4. Low temperatures.
5. Chemical reaction.
6. The solubility of rock-forming minerals under ordinary conditions.





THE AUGUSTA NATURAL BRIDGE (SEE PAGE 507), COMPARED WITH THE CAPITOL AT WASHINGTON AND THE GREAT PYRAMID

HE COLOSSAL BRIDGES OF UTAH

A RECENT DISCOVERY OF NATURAL WONDERS

BY W. W. DYAR

WITH PICTURES BY HARRY FENN, FROM PHOTOGRAPHS

IN the winter and spring of 1902 Mr. Horace J. Long was engaged, with a party of miners, in prospecting and placer-mining in the uninhabited region along the cañon of Colorado River in southeastern Utah. ng one of his lonely trips of over fifty s to the nearest post-office at Hite, ı, Mr. Long fell in with a cattleman ed Scorup, who, a few years before, ranged his cattle toward the borders olorado, over the barren and broken ıtry in the angle between the San Juan r and the Colorado.

ı the course of conversation, Scorup e of certain very wonderful "arches" h he had seen near the head of White ɔn in San Juan County. Long had ı heard the term "arches" applied in found. He therefore naturally supposed at first that these were the sort of arches that Scorup referred to, and took but little interest in the matter. But as Scorup continually recurred to the subject, and described the objects more particularly, it gradually became clear that his arches were natural bridges, spanning a wide and deep cañon from side to side.

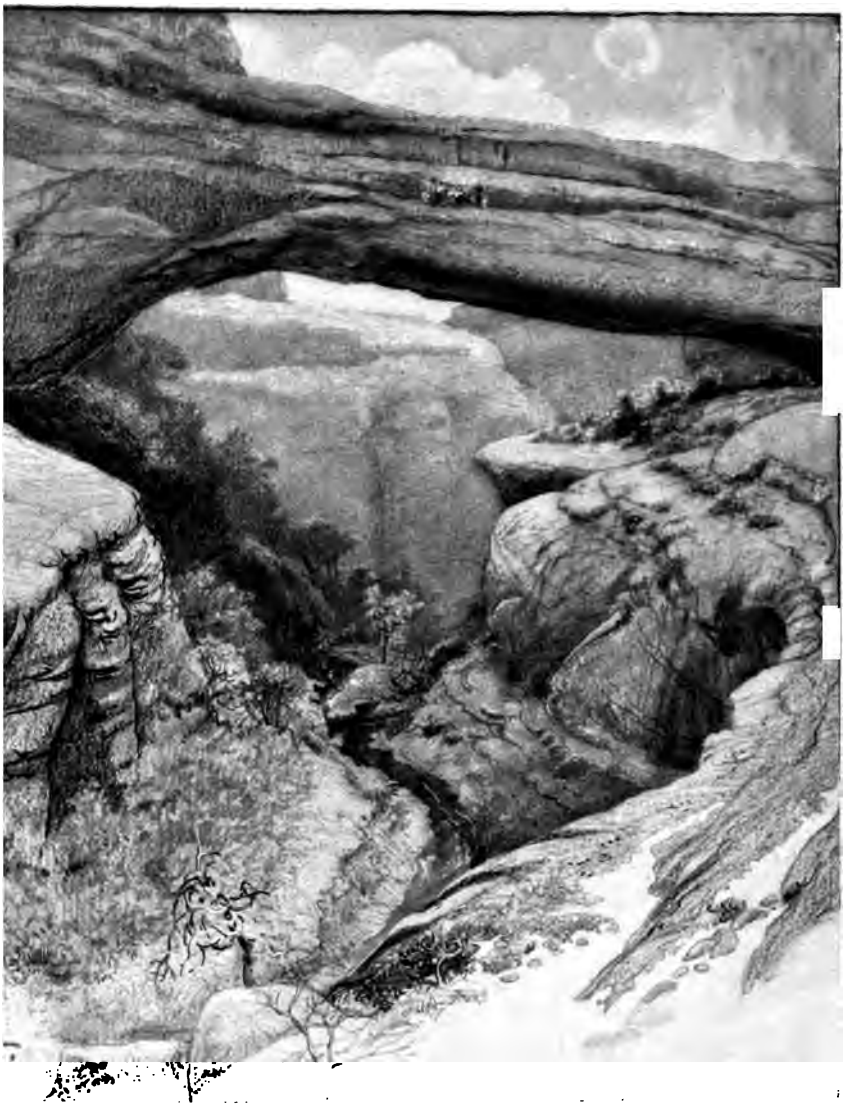
Mr. Long's curiosity was aroused, and he soon became convinced that these arches or bridges greatly exceeded in size and grandeur any similar natural curiosities then known to exist in any part of the world. From Scorup's statements it seemed probable that they had never been seen by any of the white race, save perhaps a half-dozen cattlemen and cow-boys and possibly an occasional fugitive from justice. So far as Scorup knew, they were first discovered by Emery Knowles, in 1895.

Cañon almost inaccessible by ordinary means, except in the early spring, when the melting of the light snowfall afforded a temporary supply.

Scorup greatly desired to revisit this remarkable region, and wished especially to obtain photographs of the bridges. He believed himself to be the only person then living in Utah who knew their exact location. He offered to conduct Mr. Long thither, but annexed to his offer the condition that one of the arches should be named the "Caroline" in honor of his mother.

On March 13, 1903, Scorup and Long set out from Dandy Crossing, on the Colorado River. They had two saddle-horses, and two pack-animals carrying provisions and supplies for a week's journey. They traveled in an easterly direction, following a scarcely discernible trail over barren wastes of rocks and sand. They camped the first night at Fifteen Mile Crossing, which is about three miles beyond Copper Point. Fifteen Mile is a small wash or gulch opening into White Cañon, and, like all the smaller watercourses in that region, is entirely dry most of the year. They took their horses down into White Cañon for water, cooked their supper by a fire of desert scrub, and slept in their blankets on the bare sandstone bed-rock. The next forenoon, at a place called Soldiers' Crossing, they came upon rougher and more broken with out ledges and buttes, and by mid-a the travelers descried the Elk M with dark masses of pines upon the Toward evening they passed thr opening in a rocky ridge stretchi wall across the country, and desce tortuous course of a small wash lea the chasm of White Cañon. Th they camped on a cliff-dweller which, contrary to the usual habi wary people, was only about th above the bottom of the cañon a accessible. The foundations of th dwellings were still easily trace near them was a large, flat stone f ing grain. The most perfectly p structures were large, round und receptacles like cisterns, which served as granaries. The inter were covered with a hard, perfe served cement, and there were l stones cut to fit the circular These stones, when in place, for of the floor of the dwelling.

On the morning of March 15, Scorup were early in the sadd were in the immediate vicinity bridges, and Long has confessed ing excitement as they turned the heads up the cañon. Scorup showed signs of nervousness, as hensive that his memory had



Half-tone plate engraved by S. Davis

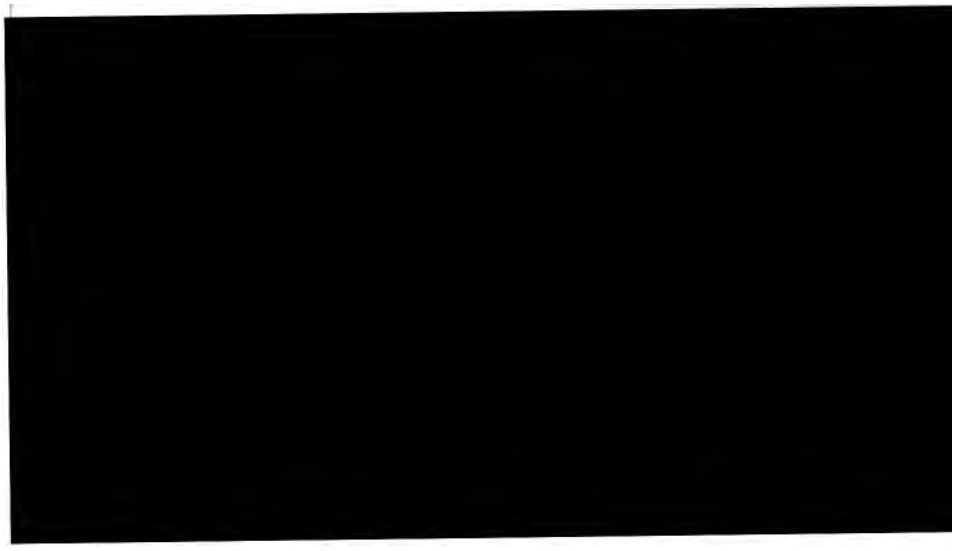
THE CAROLINE BRIDGE

-wall and had their first view of
orup's arches. Extravagant in-
have been their expectations to
any disappointment at sight of
al natural bridge before them.
the scenic point of view, this
s the least satisfactory of the
ch they visited. Its walls and
are composed of pinkish sand-
[illegible] with green

the arch tends to dwarf the height and width of the span. The travelers had with them no scientific instruments for making accurate measurements, but by a series of rough triangulations Long obtained results which are doubtless correct within narrow limits. This bridge, which they named the Caroline, in compliance with Scorup's stipulation, measures two hundred and eight feet six inches from buttress to but-

THEY WERE SHOOTING AT US WITH ONE OF THE SMALL CANNON

(1) Colossal Natural Bridges of Utah,
See National Geographical magazine, September 1904
pp 366-369, also see -
Century magazine, august 1404, article
by W.W. Dyar -
"three great arches described, are in White
canon, 2 days march from Dandy Crossing on Colo. River.
one = 208 ft 6 in from buttress to buttress
and is 197 ft high, "and over the arch
at its highest point the solid mass of S.S.
rises 125 ft further to the level floor of the
bridge." The floor of the bridge is 127' wide
called the Caroline
second bridge = "this bridge would overspan the
capitol at Washington and overtop the dome
by 61 feet; and if the loftiest tree in
the Calaveras grove of giant Sequoia
in Calif - stood in the bottom of the
canon, its upmost bough would lack
32 ft of reaching the under side of the arch."
The bridge is of "white or light colored S.S."
called the Augusta bridge -
Third bridge = called little Bridge has a
span of 211 feet + height of 142 ft. The
crown of the arch is 18 ft 8 inches thick
+ 33 ft 5 in. wide -



Terraced lime deposits.*

Hardening of beach sands by ocean water containing CO_2.

Examples on the northeast coast of Brazil. (Plates V and VI, and p. 70.)

Hardening of dunes of calcareous sands by CO_2 from the air.

II. *When the temperature is lowered.*

Hot water dissolves more mineral matter (except carbonates) than cold.

Hot waters usually deep seated, and on approaching the surface cool and deposit.

Example: box from the Comstock mines.

Some hot springs and geysers deposit tufas.

Quicksilver deposited in cool neck of retort.

When hot water is alkaline it dissolves silica and deposits siliceous sinter.†

III. *When the temperature is raised.*

Examples: marls of Michigan and Indiana.‡

Effect of heating hard water in boilers.

IV. *When the pressure decreases.*

All underground water is under hydrostatic pressure.

Pressure decreases as the water approaches the surface.

Coöperates with lower temperature, in the case of waters from depths, to help fill cavities with mineral matter from depths.

V. *When chemical reactions take place.*

Any reaction that causes precipitation.

Examples: oxidation of iron in solution, and deposition of bog iron.

Probable relations to certain ore deposits.

Some deposits appear to have been formed at the confluence of underground streams.

I. *Cutting off an arm of the sea.*

Origin of the salt in the ocean: it was all originally in the hot rocks of the earth.

Water leached it out and concentrated it in seas.

Effect of the separation of any part in dry climate.

Examples: salt spray pools on sea beaches.

Influence of an arid climate.

Waters of the Red Sea, and of Mediterranean Sea,* now denser than ordinary ocean water, in spite of the constant influx of fresh water.

Cause of greater density of waters of the tropics.

Results of isolation depend on the relations of influx to evaporation.

A salt lake may wash out and become fresh.

San Francisco bay, if cut off, would wash out.

Sea of Galilee kept fresh by inflow and outflow to Dead Sea.

The Caspian Sea was formerly connected with the Black Sea; it is now isolated and concentrating.

II. *Concentration from fresh-water streams.*

River waters contain salt, epsom salt, and carbonate of lime, etc.

Waters flowing from sedimentary rocks all contain salt, etc.

If such waters evaporate, the salt is deposited.

If their basins overflow, the water remains fresh.

It is therefore a question of evaporation or of aridity.

The western tributaries of the Paraguay river are more or less salty, because they flow from an arid region.

The eastern tributaries are fresh, owing to the greater rainfall.†

Salt Lake, Utah, covers 2,000 square miles; it formerly covered 50,000 square miles, and was fresh.‡

Its waters are now more dense than those of the ocean.

The Needles
Edson
Siberia
Cadiz
Bill Williams Fork
San Bernardino
COLORADO RIVER
Indio
Salton
Norton's Ldg.
GILA RIVER
San Diego
CALIFORNIA
Yuma
ARIZONA
MEXICO
Todos Santos B.
La Encinada
St Thomas
PACI

ARIZONA

Thickness of salt beds (maximum):
Syracuse, N. Y., Warsaw, N. Y., 65 to 318 feet
Kansas,* 200 feet.
Michigan, 32 feet.
Goderich, Canada, at 964 to 1,180 feet it is 14 to 40 feet.
Orange Island, Louisiana, 1,865 feet.
Spain, 300–400 feet in hills near Barcelona.
Stassfurt, Germany,† 4,794+ feet.
Explanation of great thickness of salt beds.
Influx of sea-water at high tide and during storms.
Examples: Lagôa de Freitas, Rio de Janeiro.
Influx due to evaporation in shallow marginal pools.‡
Interpretation of gypsum and salt beds.
Indicate salt lakes and arid climates at those places at the time of their deposition.

Alkaline Lakes.

Alkaline lakes have been formed by the concentration by evaporation of waters flowing over *igneous rocks* (in which *alkaline carbonates* predominate).
Mono Lake, California;§ area 87 square miles in 1887, but varying.
Strong solution of salt and carbonate of soda (42.53 per cent. of the total constituents).
Carbonate of lime, and borate of soda.
Old shore line 680 feet above water (higher in glacial epoch), and hydrographic basin of 7,000 square miles.
Region arid mostly; the minerals will precipitate soon.
Owen's Lake, California.
Water used to manufacture soda.

1 litre (1000 c.c) in pacific will deposit 2.5877 gram
spec. gr. salt crystals = 2.13

1 litre will deposit $\frac{2.5877}{2.13}$ = 1.215 cu. contents

or 1000 c.c. sea water (Pacific will deposit 1.215 c.c. salt

$\frac{1000}{1.215}$ = 822.1 Centimetres deep will deposit 1 c deep.

822.1 m. deep deposits 1 m deep.

822.1 ft " " 1 ft "

Salt 200 ft thick in Kansas required equivalent
of 822.1 × 200 = 164,420' deep-ocean, or
(@ 5 times greatest known depth of ocean
(Pacific deepest = 27,930')
Siccusfurt 4,794' thick required = 3,941,147' deep.
can happen by water continually flowing in thro
narrow inlet as Bosporus + continual concen-
tration if inland sea is in arid region.

Resumé.—The matter of chief geologic importance regarding all lakes, and other bodies of mineral waters, is that their mineral contents have been dissolved from the rocks over and through which they have passed, and that the nature of their contents must vary with the nature of the rocks.

The Depth to which Waters Penetrate the Earth's Crust.

Depth to which waters penetrate suggested by—

I. *Hot waters.*

Earth's temperature increases downward.

Not uniform; varies with crust and place.

Average about 1 degree for 50 feet in depth below constant line.

Reasoning from temperatures of hot springs.

Thermal Springs of Bath, England, 120° Fahr.

If surface temperature of water were 40°, the additional 80° would be had at 80×50 feet = 4,000 feet.

Hot Springs of Arkansas, temperature:

142°

—40° temperature at surface.

102° above normal temperature.

102×50 feet = 5,100 feet, depth from which the water would have come if the conditions were average.

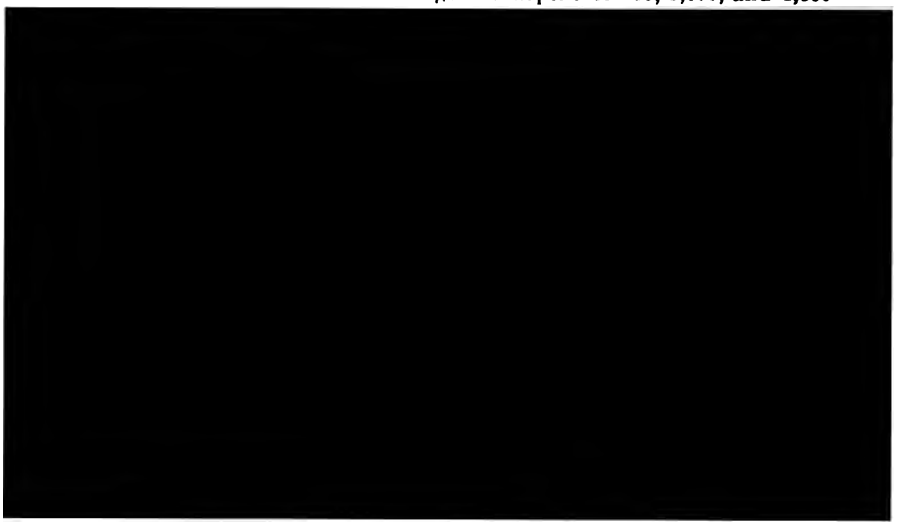
II. *Depth to which rocks are altered by decay.*

Suggests the depth to which surface waters penetrate.

In Brazil, cuts of 100 feet; drill holes, 393 feet; mines, 400 feet.*

Certain minerals (iron and copper sulphides) susceptible of change to carbonates, oxides, etc.

In mines some are found changed to depths of 600, 1,000, and 1,500



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OPERATIONS OF CHEMICAL AGENCIES.

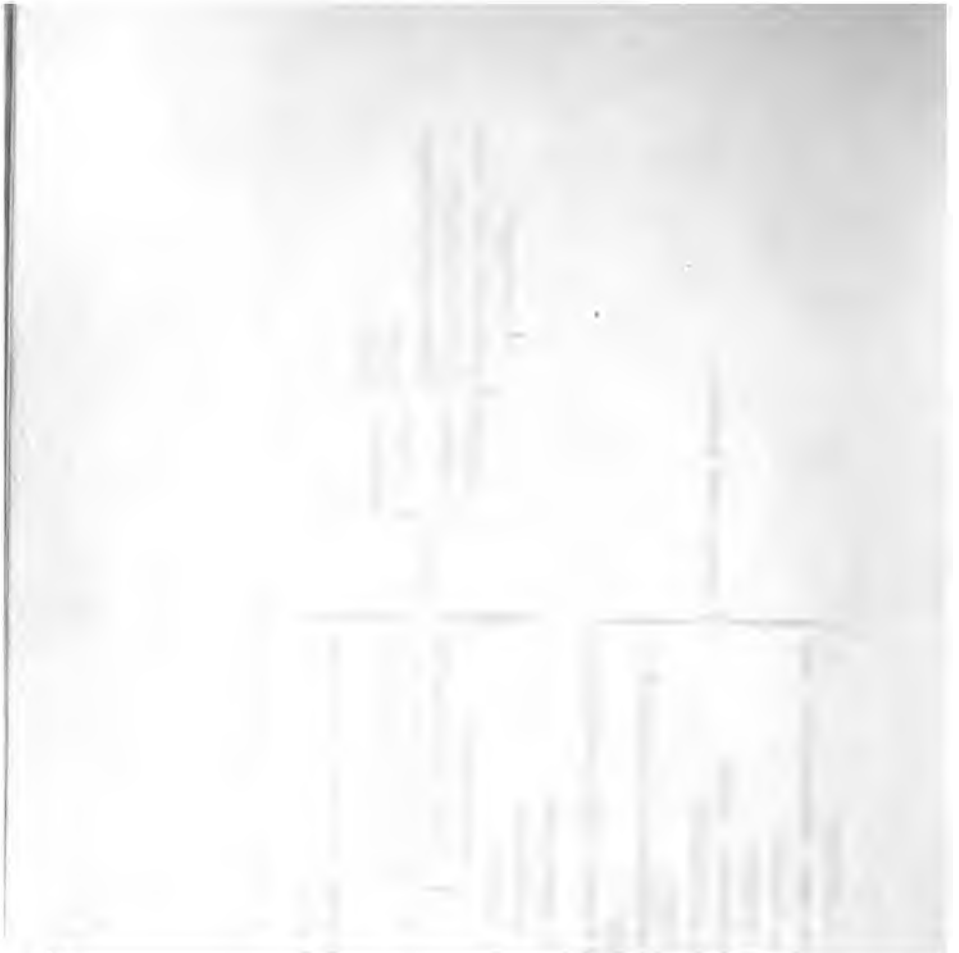
the air.
d in air from electric discharges.
CO_2 in soil.
CO_2 from organic decay.
cids — Humic acids in soil from plants, and insects, and other animals.

of pressure.
of temperature.
of temperature.

f solvent (CO_2) forming stalac-
ifas.
of temperature; hot spring de-
veins.
of temperature.
of pressure; veins.
l reactions.
of solutions.
ion and concentration; salt,
n, borax, soda.

Results:
- Residuary products: Soils. Clays.
- Alteration products: Gypsum from anhydrite. Kaolin from feldspar. Serpentine from olivine (or chrysolite).

Results: new minerals.



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IGNEOUS AGENCIES, OR HIGH TEMPERATURES.

The Interior of the Earth.

Evidences of the heated condition of the earth's interior.

1. Downward increase of temperature in wells and mines.
   (See page 138.)
2. *Volcanoes* with their accompanying phenomena.
   Explosions, steam, hot vapors and gases, molten rocks.
3. Geysers and other hot springs, bringing high temperatures to surface.
4. Positions and characters of certain rocks, such as dikes and lava sheets, which appear to have been fused, and to be connected with masses penetrating the earth's crust.

Influence of interior heat on climate.

Not felt now; in one year would not melt 1 mm. of ice over the globe.
Its influence felt only during the early history of the earth.

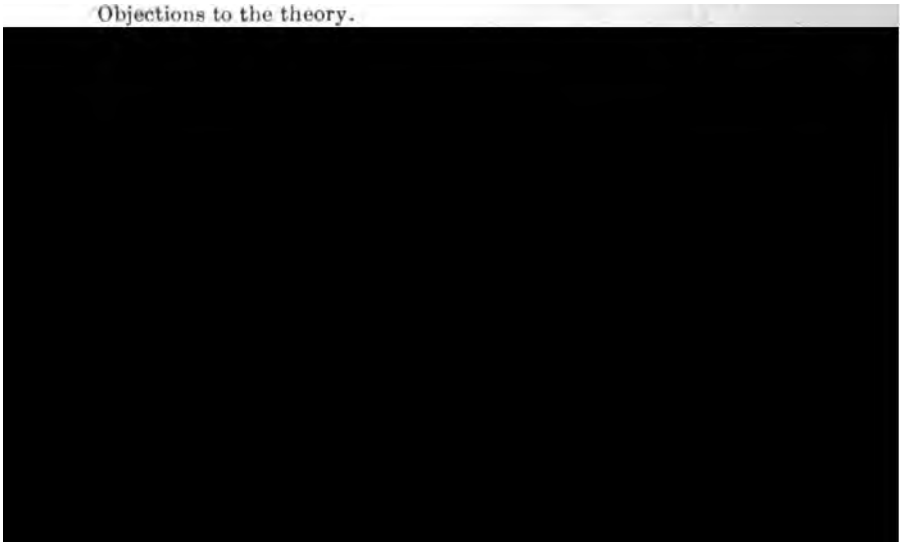
Theories Concerning the Interior Condition of the Earth.

I. *Fluid molten interior, with hard crust.*

Reasons for the theory.

Outflow of lavas and hot waters; high temperatures.

Objections to the theory.



Level of no change in the tropics is about 4 feet deep; at New York it is about 50 feet deep.

Further north it is deeper.

Difference due to climatic fluctuations.

Below the line of uniformity the temperature rises.

The increase is constant, but the rate varies at different places, and at different depths.

On volcanic cones the high temperature is near the surface.

Comstock Lode, Yellow Jacket mine.*

1° for every 28 feet, down to 3,000 feet.

Artesian wells increase 1° for about 50 feet.

North of England, 1° for 49 feet.† Committee of the British Association prefers 64 feet for 1°.‡

New South Wales, 1° for 80 feet.†

Schladebach hole, near Leipzig, 6,560 feet, 1° to 56+ feet.

Idaho-Maryland mine, Grass Valley, California, 1° to 107 feet.§

Wheeling, West Virginia, 5,386 feet, Feb. 1897, 1° to 80–90 feet in the upper half; 1° to 60 feet in the lower half.‖

Calumet and Hecla copper mines, Michigan, 1° to 224 feet, to a depth of 4,700 feet.¶

In Dakotas varying from 17½ to 45 feet to a degree.**

Variations may be due—

1. To varying conductivity of the rocks (which are not everywhere the same).

2. To varying conditions that produce high temperatures.††

Temperature of 3,000° would fuse rocks.

$$\frac{3{,}000}{50} = \text{feet descent for each degree.}$$

[redacted]

Possibility of fusion being due to local relief of pressure, as in the case of the steam of geysers.

Lava supposed to come from a depth of less than 30 miles.*

Ridging of the crust by contraction of the globe.

Pressure at six miles makes rocks plastic and closes cavities.†

Volcanic activity is mostly confined to regions of breaking, slipping, faulting, and thrust.

In any case the *igneous, or high temperature, phenomena are mostly deep seated*, though they manifest themselves at the surface.

Volcanoes and Their Geologic Work.‡

Volcanoes may be classified as —

1. *Active.*
2. *Dormant*, or extinct.

The periodicity of volcanoes is so irregular and uncertain that such a classification is quite arbitrary. Dormant, and even extinct, volcanoes become, or are liable to become, active.

I. Active Volcanoes.

Definition.—A volcano is usually a conical hill or mountain, with an opening (one or more) through which molten rocks, gases, and cinders escape from the hot interior to the surface. The mountain is the result, not the cause, and is not an essential part of a volcano.

Eruptions.

I. *Conditions of eruptions.*

Eruptions are supposed to be more or less affected by barometric pres-

Lava is brought to the surface by gravity, or the difference between the weight of the lava and that of the overlying rocks. The flow stops when equilibrium is again established.

II. *Periodicity.*

Stromboli, once in 4 to 10 months.

Kilauea, in Hawaii, once in 8 to 9 years.

III. *Sequence of events.*

Rumbling.

Earthquakes.

Rumblings and earthquakes are frequent in many volcanic regions, and do not necessarily indicate an approaching eruption.

Vapors.

Explosions.

Rise of lavas.

Overflow.

IV. *Phenomena accompanying eruptions.*

Lava flows quietly when dry.

Sheets on slopes, or in valleys.

Cones of lava, or lava and "ashes," or cinders.

Lava breaks through fissures on sides; due to hydrostatic pressure.

Pressure on the sides when the craters are high.

Height of South American craters.

Cotopaxi, 19,613 feet.* The following have long been extinct: Chimborazo, 20,498 feet; Antisana, 19,335 feet; Cayambe, 19,186 feet.

When the rocks contain much water the eruptions are explosive and scatter cinders and blocks.†

Gases.‡

Earthquakes.

Size and shape of streams.*
Temperature.
Effect on drainage.
Dams causing lakes and diverting streams.†
The topography is sometimes overwhelmed.‡
The great lava floods of the northwestern United States cover an area of 150,000 square miles.
Formation of caves with striated sides.

2. *Fragmental ejectamenta.*
Composition of the dust and "smoke," "sand," and "ashes."§
Some ascend 20,000 feet,‖ and even 164,000 feet in the case of the very fine dust of Krakatoa.
Lapilli.
Tuff if deposited in water.
Pumice in windrows.¶
Blocks and other fragments blown from throat.
Thrown 12 miles.**
Bombs.
Mud produced by rains in ashes; by melting ice on high peaks.††
Burying of Pompeii and Herculaneum under showers of fragmental material; Herculaneum 70 to 112 feet deep.‡‡
Destruction of St. Pierre, Martinique, May 8, 1902.§§

3. *Inclusions.*
Brought up from below.
Show relative age of eruptions.

4. *Gases, steam.*§§

Volcanic peaks (of construction) built up by ejectamenta.
Largest volcanoes are those of the Andes, 17,000 to 19,000 feet high.
Aconcagua, the highest peak of South America, 23,080 feet, is of

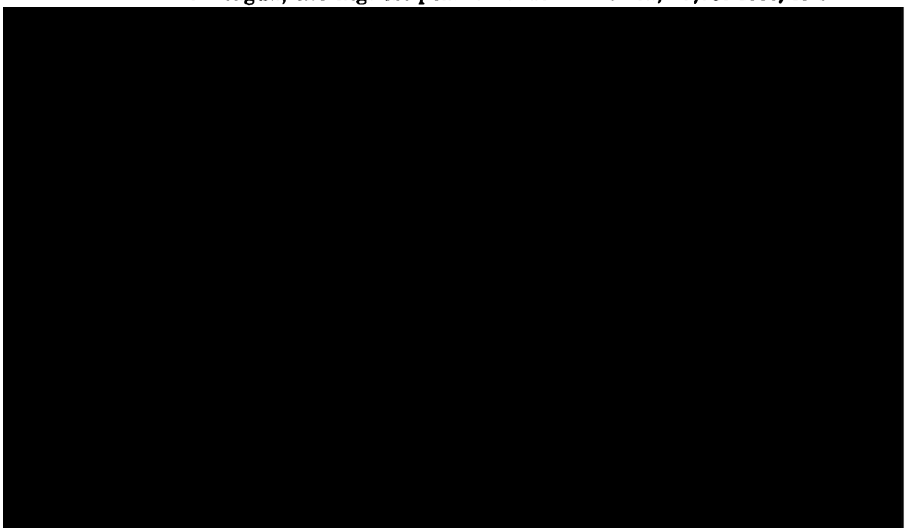


Fig. 31.—The cinder cone and lava field of the Lassen Peak district, California. (Diller.)

Ash and cinder peaks are steeper than lava cones (except locally).

The angle of repose of dry sand is 40°; of gravel is 35° to 38°.

Mt. Hood, Oregon, 11,225 feet; Columbia river cuts 4,000 feet in its lava.

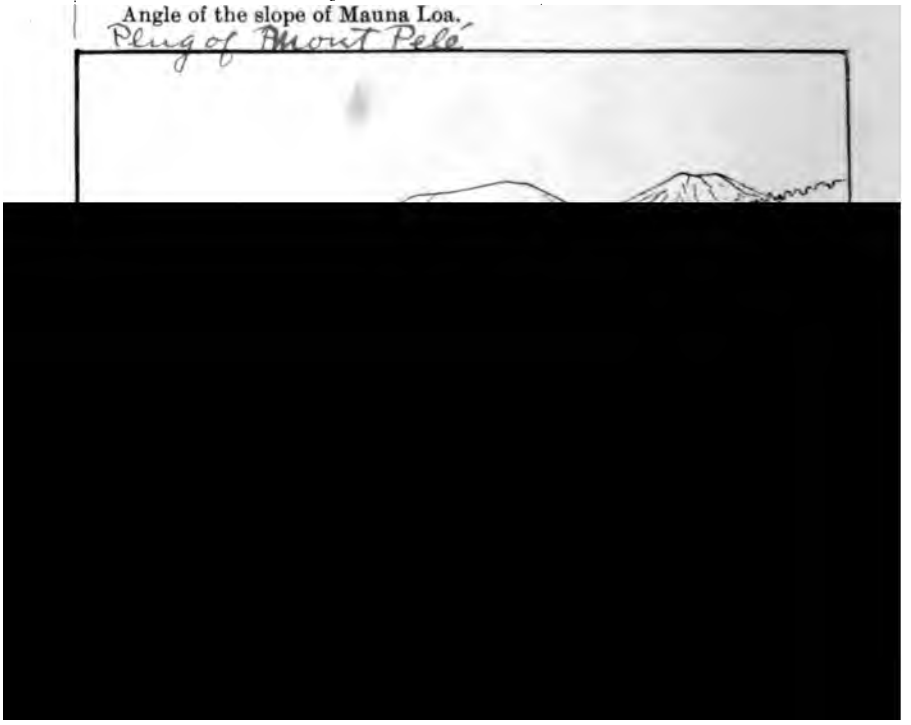
Mt. Tacoma, or Rainier (14,449 feet).

Mt. Shasta (14,440 feet) and vicinity.

Volcanic region between Lassen Peak and Mt. Shasta.

Lava cones are not so steep.

Angle of the slope of Mauna Loa.



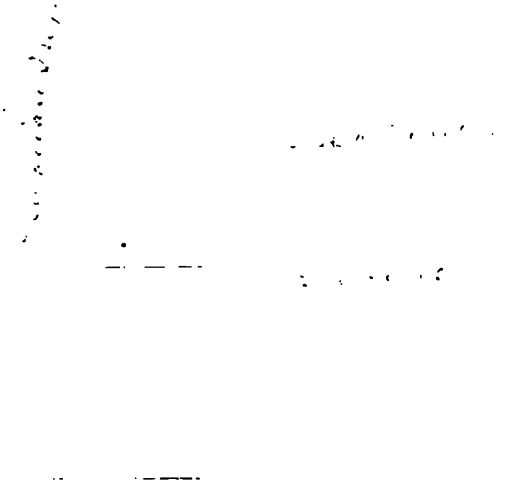


Plate X. — A volcanic crater in the Mojave Desert near Bagdad, San Bernardino county, California.

Volcanic Rocks.

Lavas, mostly dark colored.

On decay they often turn red, rusty brown, a purplish red, terra rocha.

Some are glassy, like obsidian.

Some "blistered" in appearance.

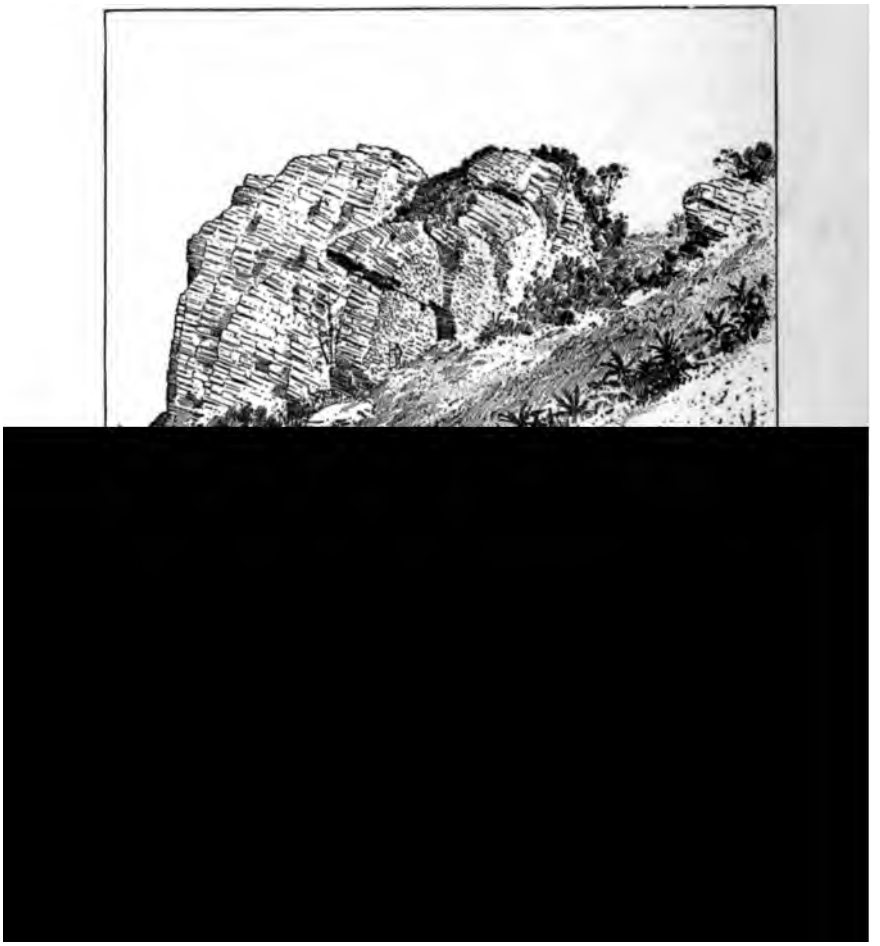
Small, angular, or rounded fragments.

Inclusions among ejectamenta.

Some lavas cool in columns, commonly hexagonal, called *basaltic*.

Examples at the Columns and at the Stone Crusher near Stanford University, Giant's Causeway. (See Plate XI.)

(For the explanation of the forms of basaltic columns see Part III of this Syllabus.



Submarine lavas are the same as terrestrial ones.*

Santorin and Theresia Islands, in Grecian Archipelago, rose from the sea 237 B. C. (Sir Wm. Hamilton, 158–9; Daubeny, 229). One of the Azores near St. Michael in 1628 (Sir Wm. Hamilton, 159).

In 1783 one (Nyöe) 6 or 8 miles off Iceland (Forbes, 286). Island a mile in circumference, washed away and only a shoal in less than one year. (Daubeny, 224.)

In 1831 Graham's Island, Sicily,† 200 feet high (a. t.), and 800 feet above bottom, three miles around. Active three weeks.

Demolished in two years.

Bogoslof island in Behring sea.‡

Volcanic islands, all deeply wave-cut.

St. Helena cliffs, 1,000 to 2,000 feet.

Teneriffe, Fernando de Noronha.

Subaqueous volcanoes on a small scale sometimes produce "mud volcanoes."§

Distribution of Volcanoes.

By sides of deepest and largest oceans.

Wallace suggests that they "take away the foundations of the surrounding district," and thus make the neighboring seas deep.‖

The distribution of certain volcanic phenomena are simulated by the outflow of water on frozen lakes.¶

Volcanic Activity Attributed to:**

1. Presence of water (they follow oceans).††
2. Contraction of the earth's crust where strains cannot be resisted, and the relief of downward pressure.
3. Permanent lines of weakness of earth's crust.

The volcanic lines are approximately the same as formerly, as if these

II. Dormant or Extinct Volcanoes.

1. Some volcanoes always active.
2. Some are quiet for years.

   Mont Pelée, Martinique, had no eruptions from 1851 to 1902.
3. Some are quiet for centuries.

   Once extinct, a volcano crumbles rapidly.

If the climatic conditions are favorable, volcanic rocks usually make good soils.

Examples of extinct volcanoes.

Crater lake,* southwest Oregon; surface, 6,239 feet a. t.; 5–6 miles in diameter; no outlet; maximum depth of water, 2,000 feet; walls above water, 500 to 2,200 feet; total depth of crater, 2,900 to 4,200 feet.

Theories of its origin.

The San Francisco mountains near Flagstaff, Ariz. Many cones to be seen from the Santa Fe and Southern Pacific railways through the Colorado desert.

Marysville buttes, California.†

The latest eruptions on the Pacific coast of the United States have taken place within historic times.‡

The cones of central France § and Germany.‖

Ancient lavas.

Cascade range volcanic.

In the Sierras on top of auriferous gravels; capping many mountains in Arizona.

Sheet near Stanford University; Frenchman's Lake, basaltic columns.

The Palisades of the Hudson is the edge of a lava sheet.

Giant's Causeway, Ireland; sheet covers 2,000 square miles.

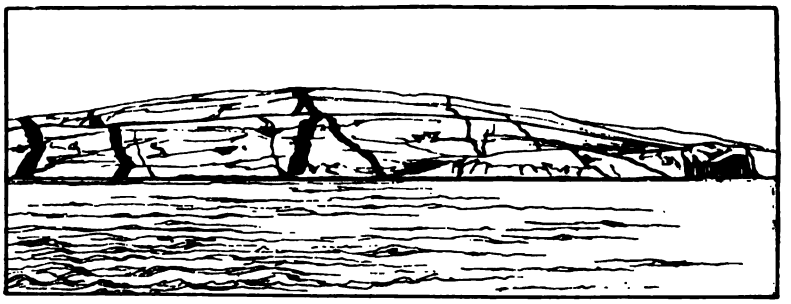


Fig. 34. – Trap dikes cutting granite, Bear Island (100 feet high), Labrador. (Daly.)

*Laccolites.**

Lavas intruded between beds.

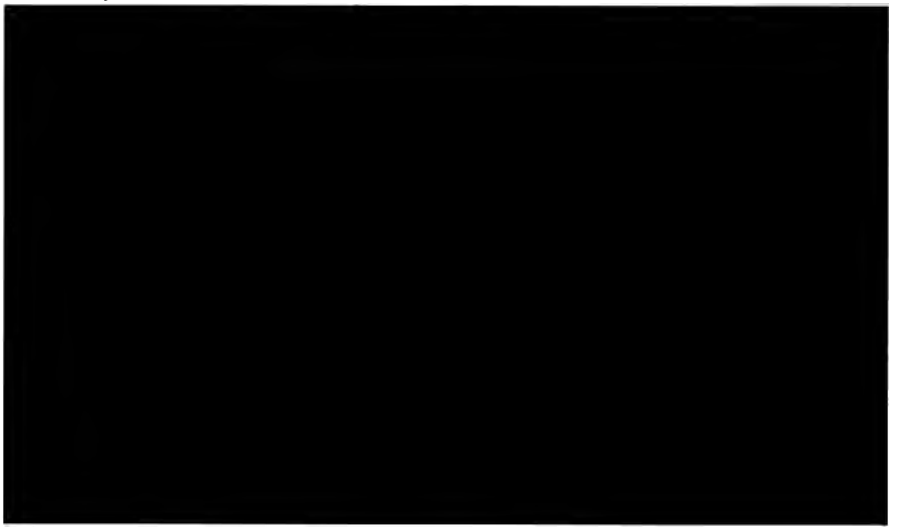
Tuffs.

Fragmental ejectamenta, often covering large areas.

Fig. 36. – The great north dike of West Spanish Peak, Colorado. At this point it forms a wall 100 feet in height. (Hills.)

Ages of Volcanoes.

Why the rocks contain no fossils except in cases of tuffs and inclusions.



Geysers.*

Geyser, a gusher. Forbes says it means "a rager"; it is applied to any noisy water in Iceland. (Forbes, Iceland, 230.)

"Geysir is a common name for all fountains, and is derived from the Icelandic word *geysa*, to ascend violently, though it is now almost exclusively applied to the great geysir." †

Geysers are *periodically eruptive hot springs.*

Always hot.

Distribution.

Iceland.

U. S. Colombia, near Cartagena on Rio Magdalena.‡

New Zealand.§

Yellowstone National Park.

All in regions of former, or recent, volcanic activities.

Phenomena of eruption of the great geysers of Iceland remarkably like volcanic eruptions.

1. Cannonading—steam bubbles collapsing like singing of kettles.
2. Bulging of water and overflow.
3. Leaping upward of water, about 100 feet.
4. Escape of steam with noise.

Frequency diminishing.‖

In 1804 the geysers of Iceland erupted every hour; now the interval is of a few days.

Dying out less marked in the Yellowstone region.

In Yellowstone National Park there are more than 3,000 vents.

Basin three miles wide, honey-combed.

Grand geyser temp. 150°, throws water 200 feet and steam 1,000 feet.

Theories of the Causes of Eruptions.

Mackenzie's theory.*

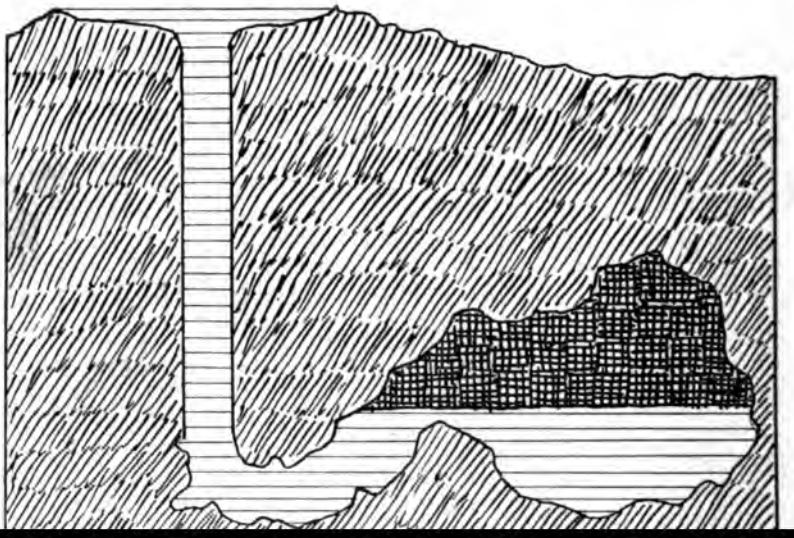
Bunsen's theory.†

Downward removal of boiling-point.

The greater the pressure, the higher the temperature required.

Artificial geysers.

Relations of the overflow to eruptions.‡



Effect of soaping geysers.
Resemblance of geyser eruptions to "bumping."
Bumping more marked in dense liquids.
Soaping increases the viscosity of the water.*
Geologic work of geysers.
Why cones are built around vents.
Relief of pressure and cooling.
Fire-hole fork of Madison river *deposits silica.*
Petrifying of trees, twigs coated.
Gardiner's river deposits travertine in terraces.†

Hot Springs.

The high temperature of hot springs caused by surface waters coming in contact with hot rocks before the waters emerge.
When the conditions of supply and emergence are favorable, geysers are formed, but otherwise only hot springs.
In most cases hot springs never have been geysers, and there is little or no evidence of hot rocks about them.
Terraces formed by hot springs.
Method of formation.
Possibility of heat being caused by —
1. Chemical reaction.
2. Burning coal.

Hot springs vary little in flow; they are deep-seated.
Supposed medicinal properties of hot springs.‡

[1] Caernarvon Earthquake of June 19th 1903 and its accompanying shocks. By Charles Davison. Quart. Jour. of the Geol. Soc, (London,) Vol. LX. (Aug. 15, 1904) pp. 233–242. Earthquake supposed to have been caused by faulting of rock - see Origin &c. on p 241, of above citation.

Concussions may be caused by—

1. Snapping of rocks under strain.
   Exemplified by the suddenness with which ice breaks in lakes.*
2. Slipping of rocks on each other. Readjustment.
3. In vicinity of volcanoes, by explosions within, possibly the forming and collapsing of steam.

To understand earthquakes it is necessary to study propagation of waves through rocks under complex conditions of various structures, compositions, and strains.

Wherever faults are common in the rocks earthquakes must have occurred, even though they may now be extremely rare.†

Every readjustment must cause jars.

Note folded and faulted *Appalachians;* faults 10,000+ feet; Scotland; Alps; faults of California.

Irregularity of sea bottom and possible slips there.

Hence, jars are to be expected along lines of weakness and readjustment. Volcanic regions are regions of readjustment.

But the wave travels at different rates, owing to the difference in the conductivity of rocks.

In loose sand, 984 feet per second; sandstone, 7,400 feet per second; granite, 9,200 feet per second.‡

Explosions at Hell Gate, New York, observed in Boston, Mass., gave a rate of transmission of 4,500 to 20,000 feet per second.

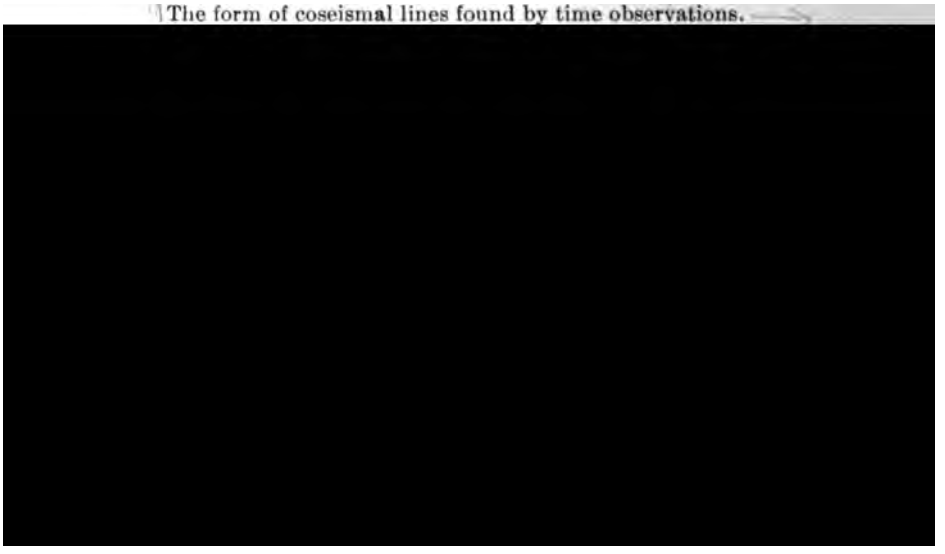
The form of the wave at the surface is determined by these differences in conductivity.

Epicentrum.

Location of epicentrum.

Coseismal lines.

The form of coseismal lines found by time observations.



A displacement of 0.01 inch is readily perceptible. (Director Campbell.)
One was reported in Japan in 1891 as "not less than one foot."*
(This does not refer to vibrations of swinging objects, or to the displacement where a crack or fault is produced.)

Form of movement.

Shown by seismograph.†
Comments on the direction of the movement.

Influence of position in relation to focus. —
At Riobama in 1797 bodies were thrown several hundred feet in the air.

Reflex action.

Effect in mines and at surface.
Sometimes not felt as strongly in mines as on top.
Cause of variation.

Frequency.‡

The frequency varies with locality; there are two a day in Japan.
Common in volcanic regions.
California is a region of faults and extinct volcanoes.
Has the weather any influence upon earthquakes? §
18279 records in Japan show that earthquakes originating on land in that country are affected by barometric pressure; yet pressure may be high without producing them.‖

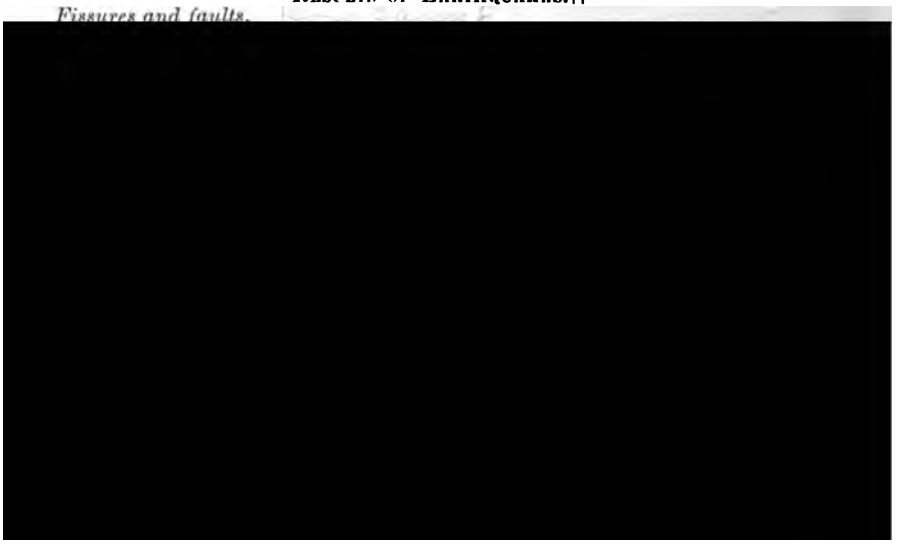
Limits of area.

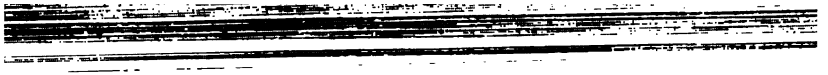
Sometimes shocks are felt over areas of thousands of square miles, even over the whole world.¶ In California they are often felt over a few miles only.

Sounds produced by earthquakes.**

RESULTS OF EARTHQUAKES.††

Fissures and faults.





The deluge of the Bible supposed to be due to the inundation of the lower Euphrates by an earthquake.*

Joints in rocks.

Rocks bend slowly, but snap when under strain, or from a sudden jar.

Earthquake waves (improperly called tidal waves) may be due to sudden lifting or lowering of the water surface.

Destruction wrought by wave.

Examples: Japan,† Lisbon.

Landslides, if in wet weather.

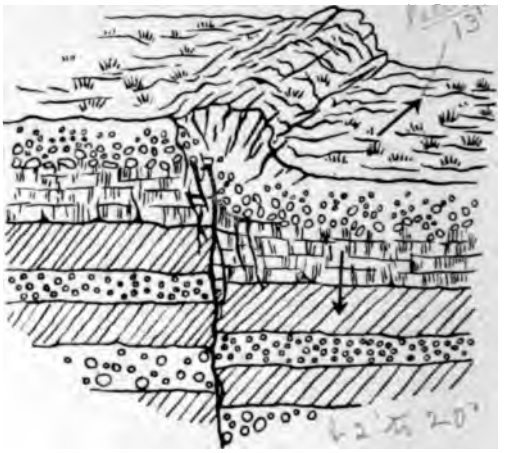
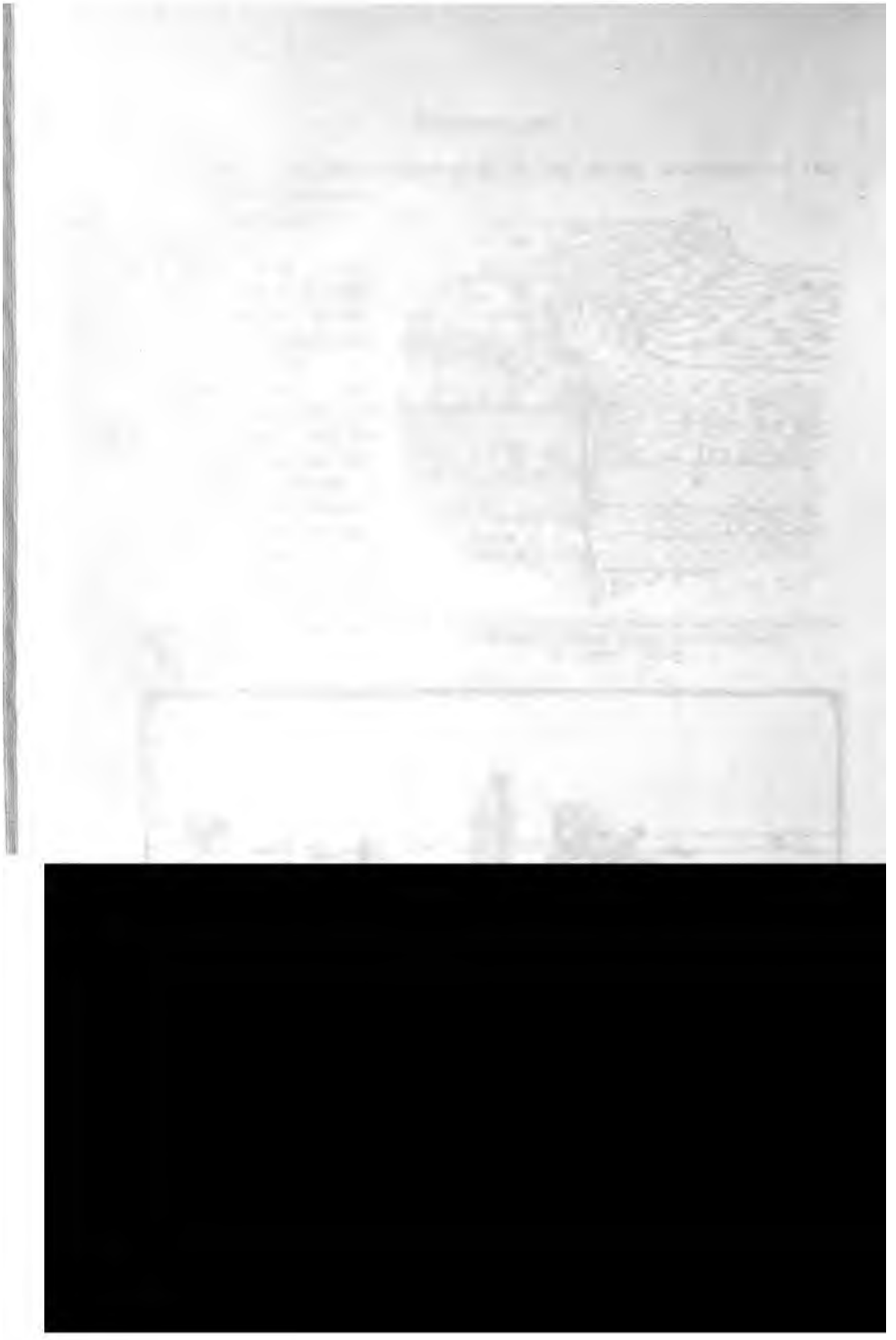


Fig. 38.—Fault having both vertical and horizontal displacement, formed during an earthquake in Japan. (Koto)



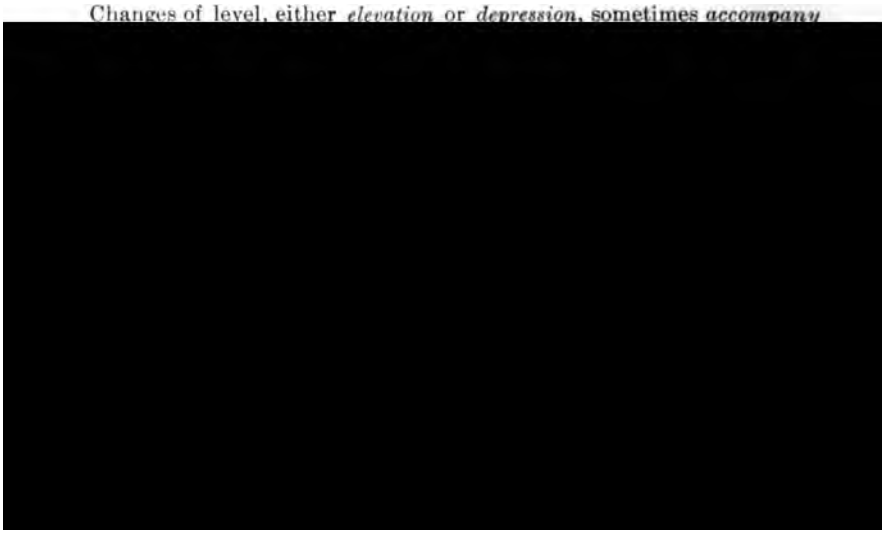
Lakes and pools formed.
Slides dam streams; breaking of such dams is dangerous.
Case in India in 1897.
Drying up of springs.
Water turned into other channels.
Terrors of earthquakes due to the fact that there is no means of predicting the time or nature of the shock, and to the instability of the earth, which is the very type of stability.
No courage or skill can prevent them.
From the faulted and slicken-sided condition of the rocks it is inferred that California always has been and probably always will be a region of earthquakes.

PRECAUTIONARY MEASURES.

Destruction of life mostly caused by the falling of walls of houses.
Catania, Sicily, earthquake in 1693; 100,000 killed.*
Lisbon earthquake, 1755, killed 60,000, but largely by wave on wharves.
Japan earthquake of 1896 killed 26,975, mostly by wave dashing upon the shores.
Riobamba, Equador. (See Whymper.)
The city of Mendoza, Argentine Republic, entirely destroyed in 1861.†
Japanese houses built of wood.
Earthquake houses placed on balls.
Destruction in California really very small.

Changes of Level.‡

Is it possible that the sea-level itself may change? §
Changes of level, either *elevation* or *depression*, sometimes *accompany*



I. *Dead marine organisms, or skeletons, on land.*

Coral reefs of St. Thomas, W. I.

Raised reefs of Mombasa, East Africa.*

Raised reefs of Cuba, 1,000 to 1,100 feet a. t.

Raised reefs of Peru, 3,000 feet a. t.;† of Lau Islands, Fiji, 1,000 feet.‡

Fossils (oysters, barnacles, and sea-urchins) on the basaltic columns near Stanford University.

Shells of Baffin Land.§ Elevation 270 to 300 feet.

II. *Work of marine animals on land.*

Sea-urchin holes about the bay of Rio de Janeiro, 3 feet a. t., and on the coast of Pernambuco. (See Plate XII.)

Pholas holes with shells at Purissima.

Pholas and worm-tubes on the Page Mill road.

Lithodomus of the temple of Jupiter Serapis, Italy.‖

III. *Wave work* (either constructive or destructive) ***now beyond the reach of waves.***

Terraces and old beaches at Santa Cruz.

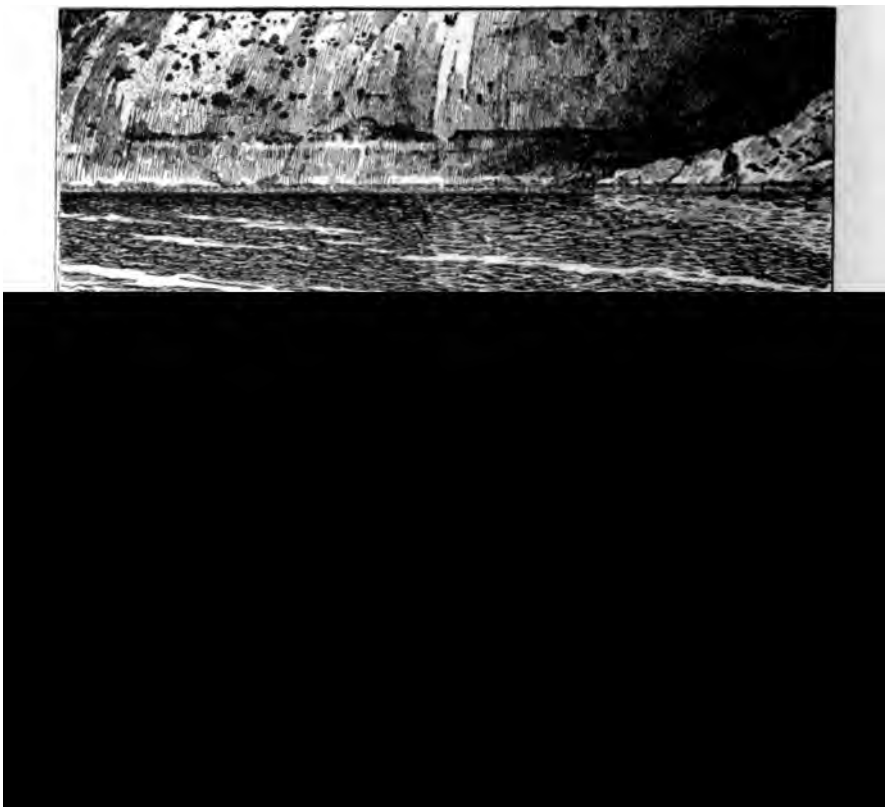


Plate XII. — Blocks of trachyte bored by sea-urchins, on coast of Pernambuco, Brazil.

San Pedro hill, near Los Angeles, terraced.
Santa Catalina islands.
Drift timber on Hudson bay above tide.*
Conflicting evidence.†
Terraced fjords of Norway.‡
Raised beaches of Baffin Land.§

IV. *Human records.*
Precise levels disclose relative land movements.
Scandinavia rising north of Stockholm at the maximum rate of 5–6 feet per century, or 0.72 of an inch in a year.

V. *An eroded surface of marine sediments.* (Unconformity is explained at length in Part II.)

Amount of Elevation.

The amount of elevation is sometimes shown approximately by the heights of marine sedimentary rocks above the sea.

Evidences of Depression.

Evidences of depression are more difficult to see, because the land surface goes beneath the water. Often it is re-elevated and uncovered.

I. *Land plants in place covered by marine deposits, or below sea-level.*
Stalactites, lignite, and erect stumps found 45 feet below sea-level in Bermuda.‖
Peat below tide on the bay of Fundy.¶
Stumps beneath marine deposits in Louisiana.
In New Jersey cedar stumps on beach reached by salt water.**
Trees in Muir inlet exposed at low tide.††
Coal beneath the sea in Peru.

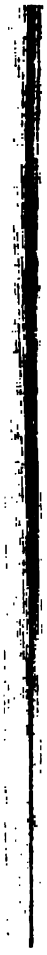
Firths of Scotland. England.*
Fjords of Norway;† coast of Maine.‡
Filled-up bays of Oceanside, California; of New Jersey.
Drowned valleys of the west coast of the United States.§
Drowned valley at New York.‖

IV. *Distribution of plants and animals.*
Identity of Santa Catalina island plants with those of the mainland.
Elephants' teeth found on Santa Rosa island and on mainland.
Elephants on St. Paul island show sinking to disconnect it from mainland.
Great Britain's former connection with Europe.¶
Wallace's work on Malay archipelago.
Professor C. H. Gilbert's work on the distribution of Pacific coast fishes.
Case of the Isthmus of Panama.**
Resemblance of the faunas of South America and New Zealand.

V. *Historical records.*
In Scania, south Sweden, some of the streets are below water.
Dunkirk fields.††
Tilting of the region of the Great Lakes.
Observations, from 20 to 37 years, show changes from 0.061 to 0.239 feet.‡‡
Spanish building at the mouth of the Mississippi river.§§
Leveling in France shows the southeastern part of that country to be fixed, while the northwest and northeast have sunk between the years 1863 and 1899.‖‖

VI. *Great thickness of sediments.*
Sediments of great thickness could accumulate only during a long and gradual depression.
Example: Arkansas Valley trough, where the coal measures (sedi-

[illegible] Indian wells [illegible] Apparently
places and 2, actually known to be
submerged, around S.F. Bay. Shell
mound, Emeryville, [illegible] at [illegible]
low tide level.



VII. *Faults with large vertical displacements.*

A fault in the coal fields of Alabama has a throw of 10,000 feet or more, and the downthrow side, with coal beds, is carried far below ocean-level.*

VIII. *Wide distribution of heavy conglomerates.*

Heavy water-worn boulders could be formed over a wide area only by the place passing through a beach condition, and this would require a gradual depression of the land.†

Distribution of changes.

No part of the earth's crust is quiet.

Behavior of delicately adjusted seismoscopes.

Some parts change more rapidly than others.

Rate of Changes.

The rate must necessarily vary greatly. Darwin mentions flat island of Santa Maria raised at a jump, and he found on land "gaping, putrefying mussel-shells, still attached to the bed on which they had lived."‡

St. Thomas raised at a jump, bringing up live corals to perish on the beach.

Gilbert cites tilting about the Great Lakes at the rate of 0.42 feet a century in 100 miles.§ The Niagara river will cease to flow in 3,000 years, if the present rate of tilting continues.

Norway, north of Stockholm, rising 5 to 6 feet per century.

New Jersey coast, from Long Island to Cape May, is sinking at the rate of 2 feet per century.

ORGANIC AGENCIES, OR THE WORK OF ORGANISMS IN GEOLOGY.

Organic agencies are *destructive*, *preservative* or *protective*, and *constructive*.

1. *Destructive organic agencies* are those that produce or hasten rock decay, such as organic acids.
2. *Preservative agencies* are those that protect rocks from destruction, such as seaweeds and mollusks, that prevent waves from cutting the shores.
3. *Constructive agencies* are those that form new rocks, such as peat from plants and limestone from coral.

I. Destructive Organic Agents.

Decay of plants and animals produces humic acids that attack minerals.*

The streams of southern Florida are charged with carbon dioxide from decaying vegetation, and as they pass through and over the limestones the waters attack and dissolve them rapidly.†

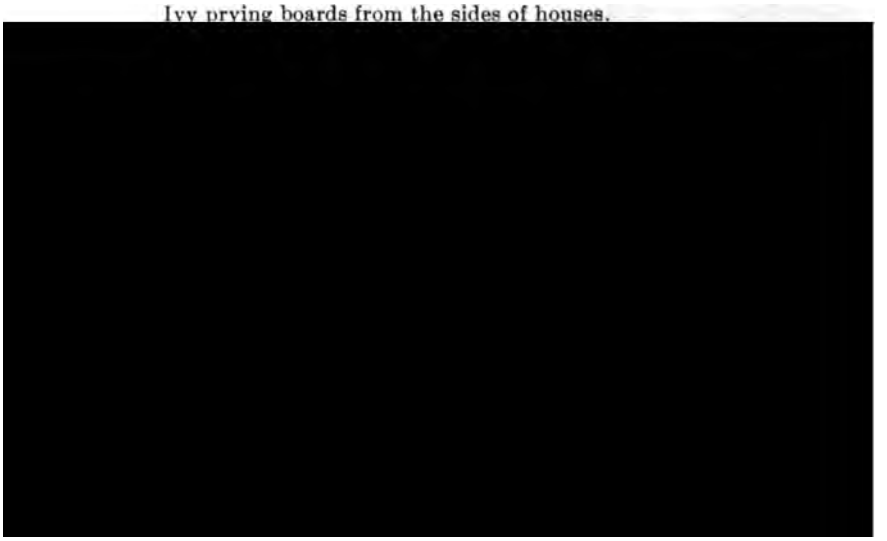
Roots of plants.

Roots etch the rocks.

Sachs' experiments on marble slabs.

Roots pry rocks apart.‡

Ivy prying boards from the sides of houses.



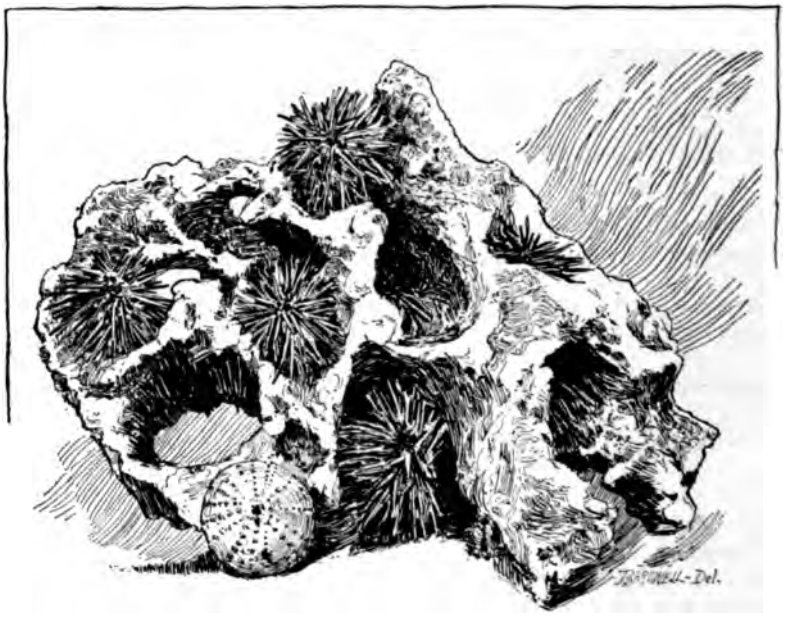


Fig. 41.—Hard rock bored by sea-urchins. From the coast of Brazil.

Boring mollusks, Lithodomus and Pholas, bore rocks.
Examples from the coast of California.
Burrowing insects, ants of the tropics.*
Worms.†

[redacted]

[redacted]

II. Preservative Work of Organic Agents.

Protection of coasts by animals.

Corals, serpulæ,* and mussels.†

Protection by plants.‡

Seaweeds;§ corallineæ (calcareous seaweeds).

Mangrove swamps of the tropics,‖ 5 to 20 miles wide. (Plate XIII.)

Bamboos of the Amazonas break the force of the current.

Bushes generally along stream and lake shores.

Water hyacinth, introduced in Florida in 1890, helps to check streams and to check scour, and to cause deposition.¶

Plants on dunes prevent the blowing of sand.

Roots of willows on canals and creeks prevent wash.

Turf protects soil from wash, and rocks from exposure and decay.

Forests on mountain slopes prevent snowslides and landslides.

Forests generally prevent the rapid melting of snow in the spring; prevent rapid flow of rain waters, and thus decrease floods and erosion.

III. Constructive Organic Agents.

Deposits.

Plants.

Carbonaceous: sphagnum, peat, lignite, coal, oil, gas.

Sulphurous.

Ferruginous: iron.

Nitrogenous: nitre.

Siliceous: diatoms (algæ), chert, ooze, silicified wood.

Calcareous: corallineæ of the algæ.

Animals.

Calcareous: corals, shells, bones, ooze.

[redacted]

Rocks of carbonaceous plant origin.	Oxygen, percentage.	Carbon, percentage
(Wood	44	49)
1. Peat	30–40	59
2. Lignite	20–35	68
3. Bituminous coal	10–15	81
Anthracite coal	1½–2½	95
4. Graphite	0	100
5. Diamond	0	100

Petroleum, asphalt, gas, and related carbonaceous minerals, are derived by distillation from organisms, but probably not from any one kind.*

The carbonaceous parts of rocks are derived from either plants or animals — chiefly from plants.

Wood contains 49% carbon and 44% oxygen (+ 6% hydrogen).

PEAT.†

Peat is woody matter that has lost oxygen, and is thus altered part way to lignite.

Antiseptic property of peat prevents decay.

Peat made of mosses (*sphagnum*) grows in marshes, and floats on, and fills, shallow ponds.

Moss dies below, grows above; generations of plants.

Changes at bottom to brownish black, cheese-like muck.

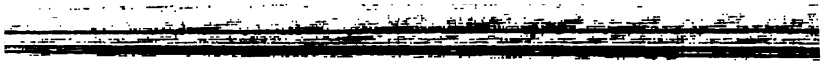
Penetrated by roots of plants growing over surface.

Covers large areas, 5 to 50 feet thick.

Rate of growth varies with conditions; 1 foot in 5 to 10 years.

Some of the European bogs have grown in 1800 years, and have stumps, roads, coins, etc., beneath them. These bogs have grown from one inch to several feet per century.

Extent



Lignite.

Lignite, or *brown coal*, is common in rocks of Tertiary and Cretaceous age.

Appears to be a further change of peat.

Change takes place very slowly and can not be observed.

Evidences of peat origin of lignite.

1. Spores found in lignite like those in peat.
2. Plant impressions the same in peat and lignite.
3. Intergadation of peat and lignite.
4. Clays beneath lignite contain roots like those penetrating the clays beneath peat.
5. Experimental demonstration.*

Interbedding of lignite and sediments.

Sections often show several beds of each.

Must have been flooded; or, if there are marine fossils, the peat-moss must have been covered by the sea.

Bituminous Coal.*

Intergradation of lignite and bituminous coal.

Change very slow; not in man's time.

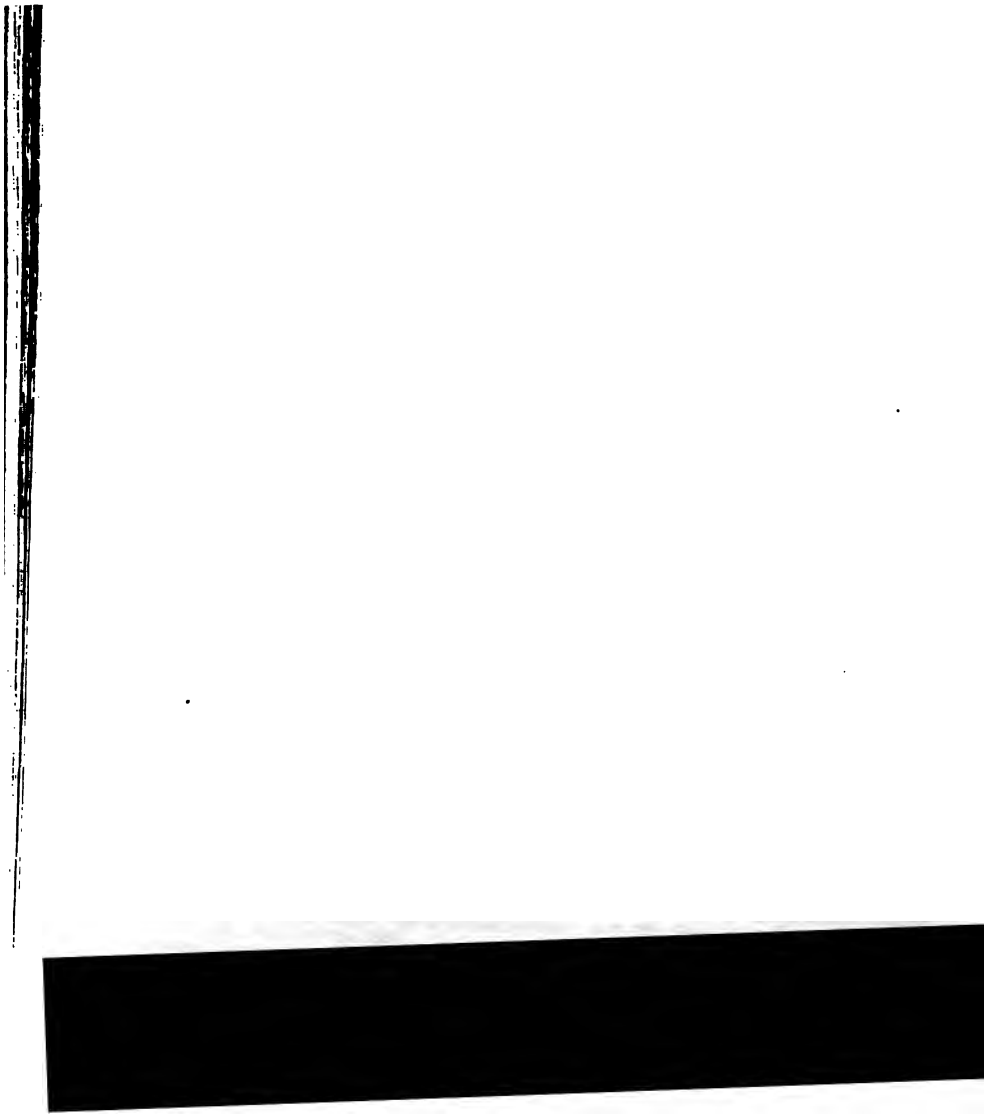
Coal not derived from marine plants, for fucoids contain 75 to 80% water.

Coal usually has clay below, with roots penetrating it.

Stumps found standing; in some cases these stems extend into the overlying clays.†

Sediments interbedded with the coal show changes by submergence and new growths.

Splitting of coal beds accounted for.‡



cipal coal fields of the United States but do not include all the lignite deposits.

Theories advanced to explain the origin of coal.

1. *Marine plants.*
   Marine plants have no wood, but cellular tissue only.
2. *Blown into lakes from the land.*
   Too widespread; area of North American coal fields.
3. *Floated timber of deltas.*
   Too much and too widespread; the coal beds are of rather even thickness; driftwood irregular and mixed with mud.
4. *Timber floated into the sea.*
   Stumps beneath the coal are rooted in place.
5. *Peat-bog theory of origin now accepted.**
   Carbon from the air.
   Renewed from the crystalline rocks and from the sea.
   Air not necessarily overcharged with carbon.†

GRAPHITE.

Graphite is produced in some cases by a still further change of coal.
Too much changed to be available for fuel.
Changed in some cases by excessive heat.
Found in the oldest rocks.
Origin of the graphite found in pig-iron; derived from coal.

DIAMONDS.

Diamonds are crystalline forms of carbon, probably formed by change of graphite by pressure and heat. Graphite found in the diamond matrix of Brazil.‡

DRIFT-TIMBER.

Sulphurous Deposits from Plants.

Certain bacteria extract sulphur from sulphuretted water (sewage works and factory effluents) and store it up as globules, known to engineers as "sewage fungi."*

In hot springs in Japan;† temperature 154° to 157° Fahr.

Only in water with hydrogen sulphide.

Ferruginous Deposits from Plants.

Iron carried in solution in streams as carbonate, loses CO_2 through the agency of bacteria, and ferric oxide is precipitated.

Nitrogenous Deposits from Plants.

Nitre or saltpeter, formed by nitrifying bacteria.‡

Siliceous Deposits from Plants.

Diatoms are low forms of microscopic plants (algæ) living in salt or fresh water.§

Abundant in fresh warm waters of Yellowstone National Park.

Temperatures up to 185° Fahr.

Deposits there 3 to 6 feet thick; called "sinter."‖

Silica extracted from the water.

Deposits consist of accumulations of skeletons.

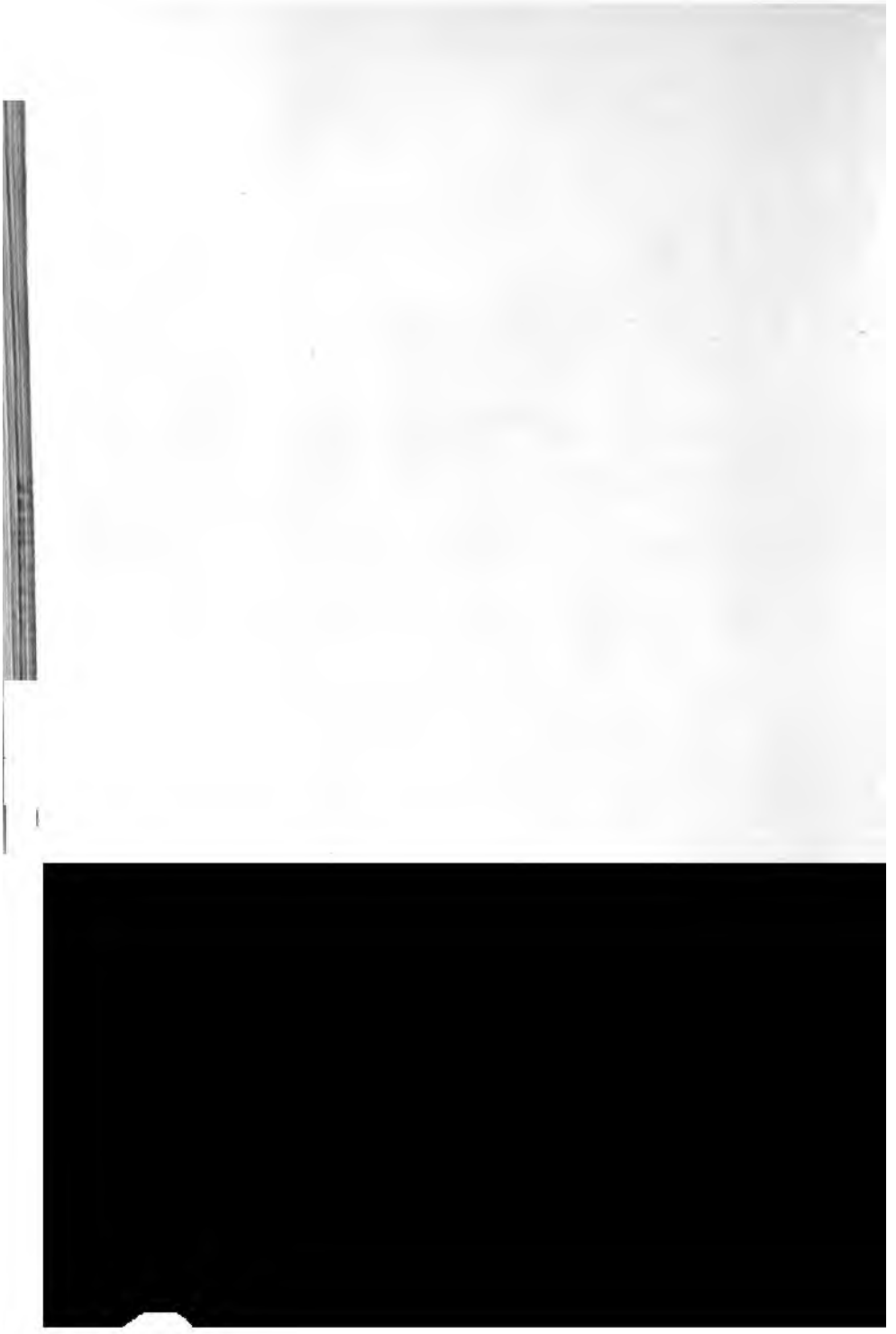
Marine diatom beds at Santa Cruz, California, are 700 feet thick.

In Nevada, 200 to 300 feet thick.

Rocks of diatoms¶ are earthy like chalk, harsh to the touch; used to polish metals.

Plate XIV*a*. — Bridge formed by a petrified tree trunk near Holbrook, Arizona. (Vroman.)

Plate XIV*b*. — Petrified logs, Chalcedony Park, near Holbrook, Arizona. Petrified wood covers an area of more than a thousand acres at that place.



Calcareous Deposits from Plants.

Nullipores or *Corallinæ* are coral-like calcareous algæ growing in salt water. They help build up coral reefs and coral sand-beaches.

Other calcareous algæ contribute to marine calcareous deposits.*

Calcareous tufas of Great Basin formed through the agency of low plant life.†

One calcareous spring in Yellowstone Park (Mammoth Hot Spring); deposits made by algæ.‡

Some calcareous oölites and marls are lime secretions of algæ.§

"Water-biscuit" of Canandaigua Lake formed by algæ taking up CO_2 and causing the precipitation of the lime from the water.‖

Animals as Constructive Organic Agents.

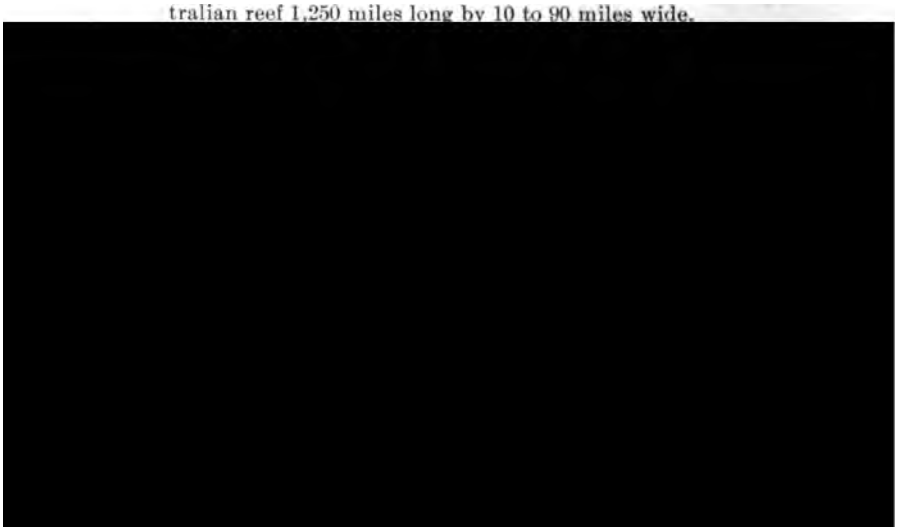
Calcareous rocks made by animals.

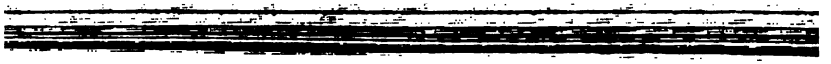
1. Corals and serpulæ whose skeletons are attached.¶
2. Shells of microscopic marine organisms living at or near the water's surface; foraminifera.
3. Shells of univalves (gasteropods), bivalves (lamellibranchs), worms, echinoderms, crustaceæ, and all animals having calcareous skeletons, whether vertebrates, such as fishes, or invertebrates, such as crinoids.

Coral Reefs.**

Importance of the subject.

1. Large areas of the globe covered by coral reefs and islands. Australian reef 1,250 miles long by 10 to 90 miles wide.





Coral rocks are formed from the skeletons of polyps.

Animals are soft, gelatinous, often transparent, of various colors.

Radiate structure with tentacles.

Carbonate of lime deposited in the lower part, which is fixed.

Form and deposition of the lime by polyps are vital functions, and not subject to will.

The growth of coral reefs is produced by growth of these deposits.

Forms of corals.

1. Loosely branching.
2. Solid, spherical, or hemispherical.
3. Tabulate.

Reproduction.

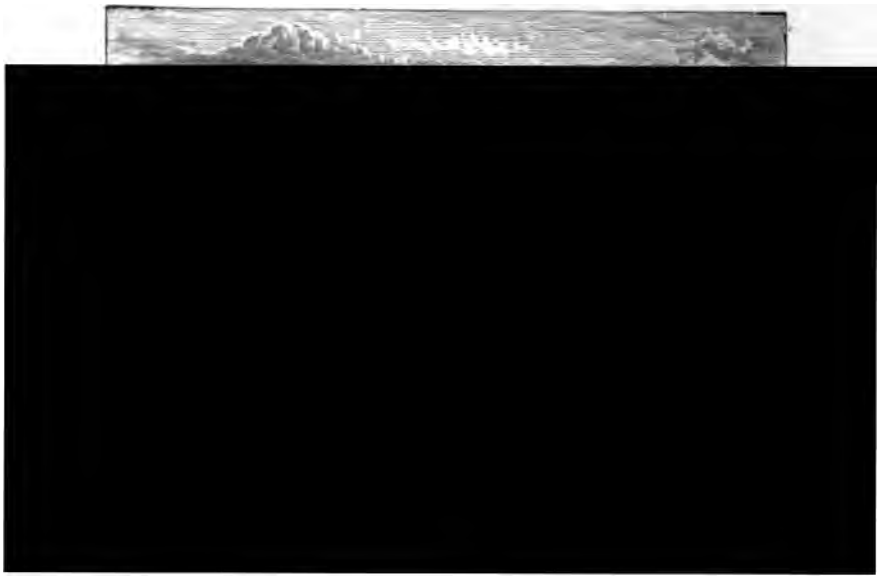
1. By eggs having power of locomotion, and floating away in the water till they attach themselves to the rocks.
2. By branching or budding.

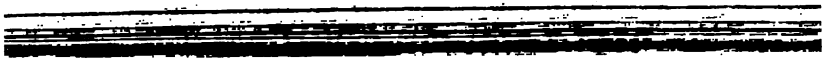
Conditions of growth of the reef-building corals.

(Reference is made here only to what are known as the reef-building corals; other corals live at great depths in the ocean, and in very cold waters, but they do not form reefs.)

1. Temperature at or above 70° Fahr.
2. A range of temperature not exceeding 12° Fahr.*
3. Depth, 150 feet and less; most favorable at 50 feet and less.
4. Clear salt water.

   Effects of elevation and depression, mud, volcanic ashes, and fresh water.
5. Constant change of water; necessity of lime and oxygen.





Forms of coral reefs.

1. Fringing: join the land.
2. Barrier: form barriers between sea and land.
3. Circular: approximately circular; enclose water; sometimes enclosed lagoons fill up.

(These forms are not sharply distinguishable, but merge into one another.)

Size of coral reefs.

The great reef of Australia is 1,250 miles long by 10 to 90 miles wide.

Theories of reef formation.

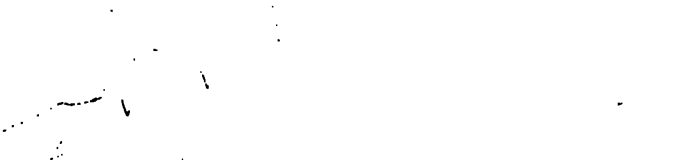
1. *Subsidence theory of Darwin.*
   - *a.* Intergration of reef forms.
   - *b.* Actual subsidence of some existing islands.
   - *c.* Depths at which reef rocks are found.
     A bore-hole sunk in 1897, at Funafuti, northeast Australia, passed through 987 feet of coral without reaching the bottom of the reef.*
   - *d.* Elevation of some reefs.
     For depression is as common as elevation.
2. *Murray's theory of submarine peaks.*
   Conditions.
   - *a.* That the coral polyps take possession of submarine peaks.
   - *b.* That when the depth is too great, accumulations of microscopic organic remains build up the peaks till they come within reach of the corals.

Murray thinks atolls grow larger by building beyond the growing depth.

Darwin thinks atolls grow smaller.

Murray's theory is not improbable.

Rate of growth of reefs.



Possibility of other conditions.

Temperatures are constantly lowering.

Life began in warm seas and climates.

The tendency is to adapt to colder conditions, rather than to originate in cold climates, and to change from colder to warmer.

Coral reefs teach that —

1. Coral limestone is made by animal growths, assisted by wave work and consolidation.
2. Coral limestones are of marine shallow-water origin.
3. They attain great thickness by subsidence.
4. Our limestones contain near-shore life, and are, therefore, of near-shore and shallow-water, rather than of deep-sea origin.

Serpulæ.*

Microscopic Marine Animals.

Foraminifera have (mostly) calcareous skeletons.

Live near surface of seas.†

Dying, their skeletons sink to bottom, forming "*ooze*."

Chalk made up of such calcareous skeletons.

Skeletons found to depths of 13,800 feet.‡

Below that depth these skeletons are dissolved by pressure and the carbon dioxide in the water.§

Bryozoa lenses of limestone.‖

Molluscan and Other Calcareous Shells and Skeletons.¶

(Worms, echini, crabs, crinoids, etc.)

Examples: coquina of Florida; conch shells on the Bahamas.**

Encrinital limestone.

Phosphatic Deposits Formed by Animals.

Droppings and bones of marine animals or birds.

Accumulate on sea bottom or on arid land.

Guano on the islands of Peru in an arid region.

No rain to wash it away.*

Phosphate rocks of Tennessee and Arkansas.

Sometimes concentrated, as in the rivers of South Carolina.

Marine organisms are most abundant in shallow waters and near shore. This is especially true in the tropics. In polar regions the fauna is more abundant in depths of 50 to 150 fathoms than in depths of less than 50 fathoms.†

We have now gone over all the *different methods by which rocks are made.* All rocks fall under one of these heads, and are made in one of these ways.

All rocks have originated as
- Mechanical sediments deposited in water, or by wind.
- Chemical deposits, deposited from solution.
- Igneous rocks from fusion.
- Organic deposits made by plants and animals.

All these deposits are subject to metamorphisms and change of position of bedding. (See Structural Geology, Part IV.)

Man as a Geologic Agent.‡

Man's work is confined to modifying the operations of nature.

Of comparatively little importance, because the element of time is wanting for his works.

1. Man's influence on plants and forests.

Other plants accidentally distributed.
Tumbleweed, Russian thistle.
Weeds along roads and railways.*
Cockle in wheat.

Man's Influence on the Forests.

By planting.

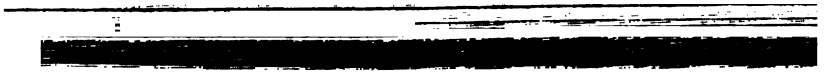
Eucalyptus, introduced from Australia; Lombardy poplars from Europe.
In Switzerland, forests planted to prevent avalanches.
On the west coast of France, for resin and to stop the shifting of sand-dunes.
Willows planted on canals and streams to prevent cutting.
To prevent landslides.

By cutting away.

Destruction of forests for lumber, charcoal, tan-bark.
Destruction by forest fires; by grazing.

1. Effects of forests on the scour of streams.
   Cutting of bamboos along streams permits scour.
   Cutting mangrove swamps permits scour of the coast: no filling.
2. Effects of forests on floods by —
   Holding back water in leaves and debris.
   Holding back snow from melting rapidly.
3. Removal of forests exposes the soil to sun and drouth, and it cracks and lets in decomposing agents.

Questions to be considered.
Do forests change climate?
What is climate?
Annual variations.
Long series of observations necessary to determine the climate.



II. *Animals distributed involuntarily.*

1. *Injurious or parasitic insects.*

Colorado potato-beetle.

Hessian fly.

Scale insects imported on fruit.

Of 73 injurious insects of primary importance in the United States, 37 are introduced, all but one, accidentally.*

Gipsy-moth, introduced in 1869 in Massachusetts, has cost a million dollars, and will cost one and a half millions more to get rid of it.

2. *Harmless animals developing into pests.*

English sparrows in United States since 1850–67.

Parrots of Australia.

Rabbits.

Marine life likely to be modified by the Suez canal and the Panama canal.

III. *Animals exterminated, or nearly so.*

1. Dangerous or injurious: squirrels, snakes, panthers.
2. Game valuable for food, fur, or hides.

Bears, beavers, buffaloes, whales, fur-seals.

3. Wanton destruction.

Birds of the guano islands.

Buffaloes.

IV. Man's Influence on the Land.

Reclaiming land.

Marshes and swamps drained (elevated marshes).

Sea marshes of Holland.

Lowering Swiss lake for land.

*Cultivation of the soil.**

Cultivation greatly increases chemical activity in soil.

1. Erosion hastened; ground not protected by plants.
2. Erosion is checked where the land is terraced, as in Switzerland.

Checking stream erosion.

Mattrasses and piles at Pine Bluff, Arkansas.

Levees of the Mississippi river, confining it to channel.

Straightening and paving the Rhone and other swift streams in Switzerland.

Using the falls for power and thus checking the cutting.

Example: Niagara Falls.

Future water storage.

Will prevent or check floods, and retard erosion.

Geological deposits made by man.

Refuse heaps about cities and towns.

Those of large cities dumped into the sea from scows and ships.

Cities buried.

By dust-storms of Africa.

Sand-dunes of Bermuda.

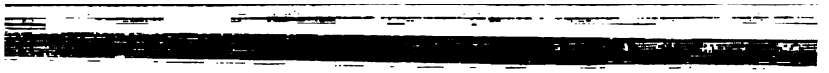
Volcanic dust of Vesuvius.

Example: Herculaneum and Pompeii.

Ocean deposits are receiving the rejectamenta of civilization and preserving them as fossils.

Distribution over the entire globe by means of navigation.

* The economic aspects of soil erosion. By N. S. Shaler. Nat. Geog. Mag., Nov. 1896, VII, 368-377.



PART II.

STRUCTURAL GEOLOGY, OR THE MODIFICATION OF ROCKS.

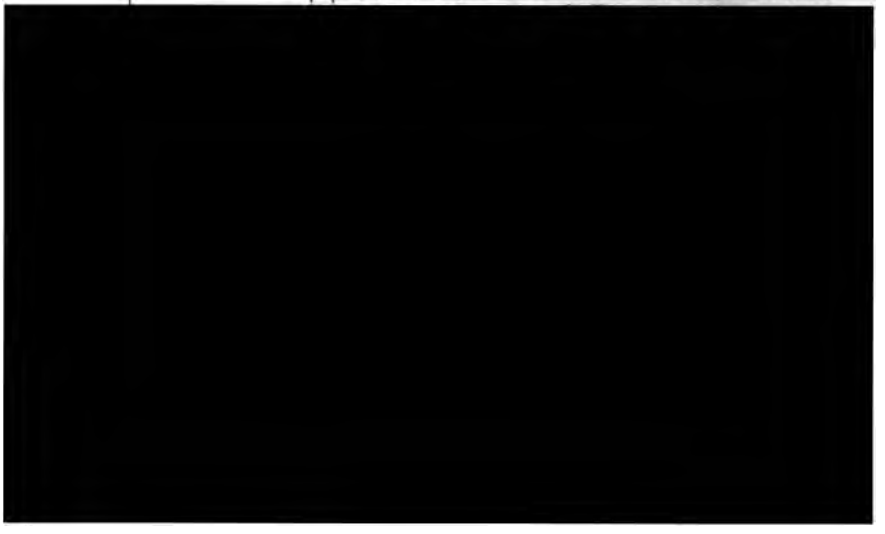
Structural Geology treats of the kinds and arrangements of rocks, and the changes to which they are subject.

Rocks are any materials forming the earth's crust.

They are (1) *sedimentary or stratified;* (2) *igneous or unstratified;* and (3) *vein deposits.*

SEDIMENTARY, OR STRATIFIED ROCKS.

			UNCONSOLIDATED.	CONSOLIDATED.
Shallow-water deposits.	Arenaceous, or sandy.		Shingle.	Breccia.*
			Gravel.	Conglomerate, pudding-stone.
			Sand.	Sandstone, or quartzite.
	Argillaceous, or clayey.		Clay.	Shale, or slate.
	Calcareous,		Ooze,	Chalk, limestone,



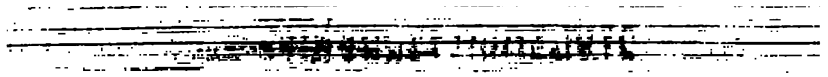
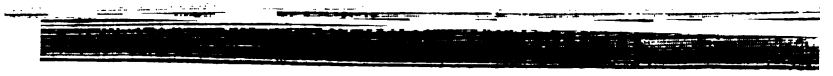


Plate XV. — Brecciated siliceous limestone cemented with dolomite spar.



Sedimentary rocks cover nine-tenths of the land, and all of the sea bottom.

They average several miles in thickness, with a maximum thickness of twenty miles.

Sedimentary rocks may be hard or soft; there is no line of demarkation between the consolidated and the unconsolidated.

There is no sharp line of demarkation between the materials of these rocks; they all intergrade.

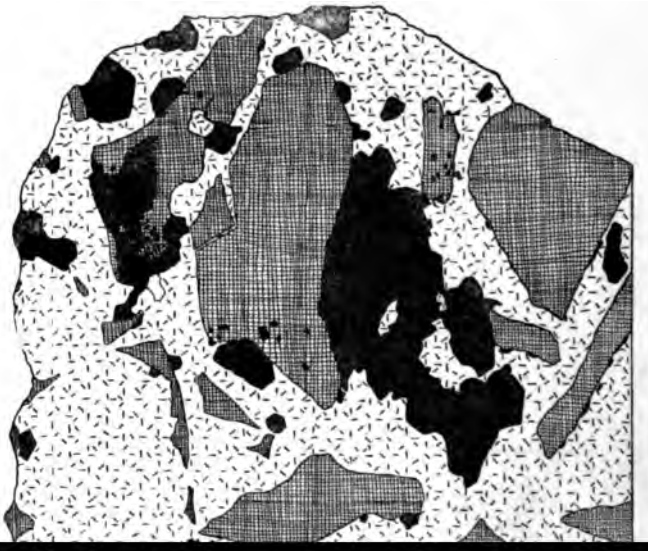


Plate XVI. — Unconformity Miocene shales below and Pleistocene beds above. Exposure on the beach two and a half miles northwest of Pismo, San Luis Obispo county, California. (Fairbanks, 1898).

Lamina, a very thin layer.

Lenticular beds are lens-shaped.

False bedding, or plunge and flow structure,* is characteristic of nearly all coarse sediments.

Produced by wind-bedding in any kind of materials.

Conformity.

Rocks conform to each other (or are conformable) when laid down in successive layers in a continuous deposition.

Unconformity indicates interruption.† (See Plate XVI.)

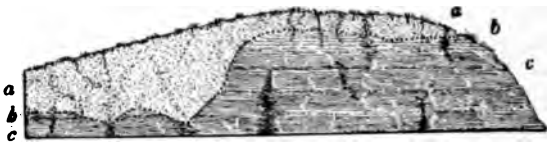


Fig. 47.—An unconformity (*b*) between Tertiary (*c*) and later (*a*) beds. (Harris.)

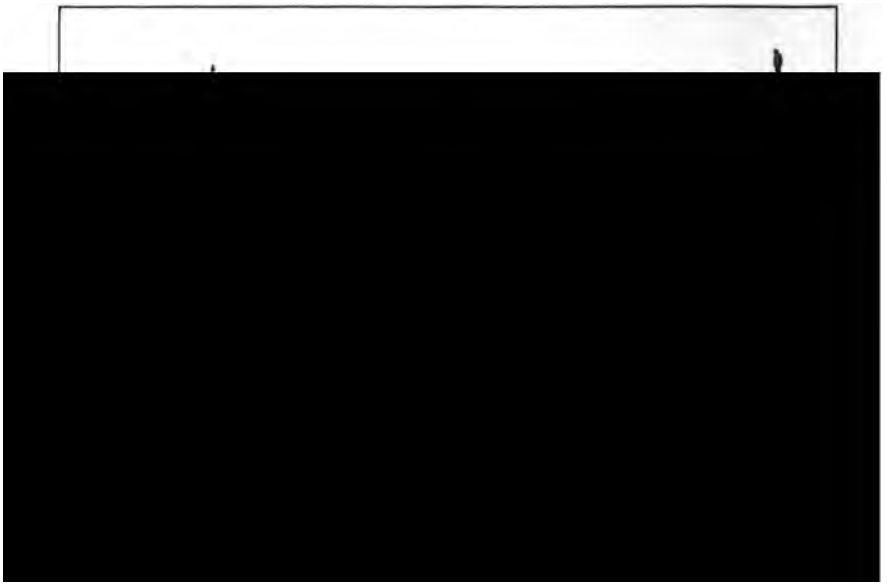
Impressions during deposition.

Ripple-marks are found in sediments in the bottom of rather shallow water.

They are made by the vibration of the water up to a depth of 450 feet.‡

Ripple-marks are visible on the bottom of Lake Geneva, caused by the paddle-wheels of steamers.

Giant ripples caused by wave interference in shallow water.§



Rain-prints.

Sun-cracks.

Tracks of birds and other animals.*

Fossils are the hard parts, or impressions, of animals or plants that die in the water, or are washed down from the land.

Alternation of beds is produced by the—

1. Varying conditions of supply.
2. Changes of currents.

Persistence of strata.

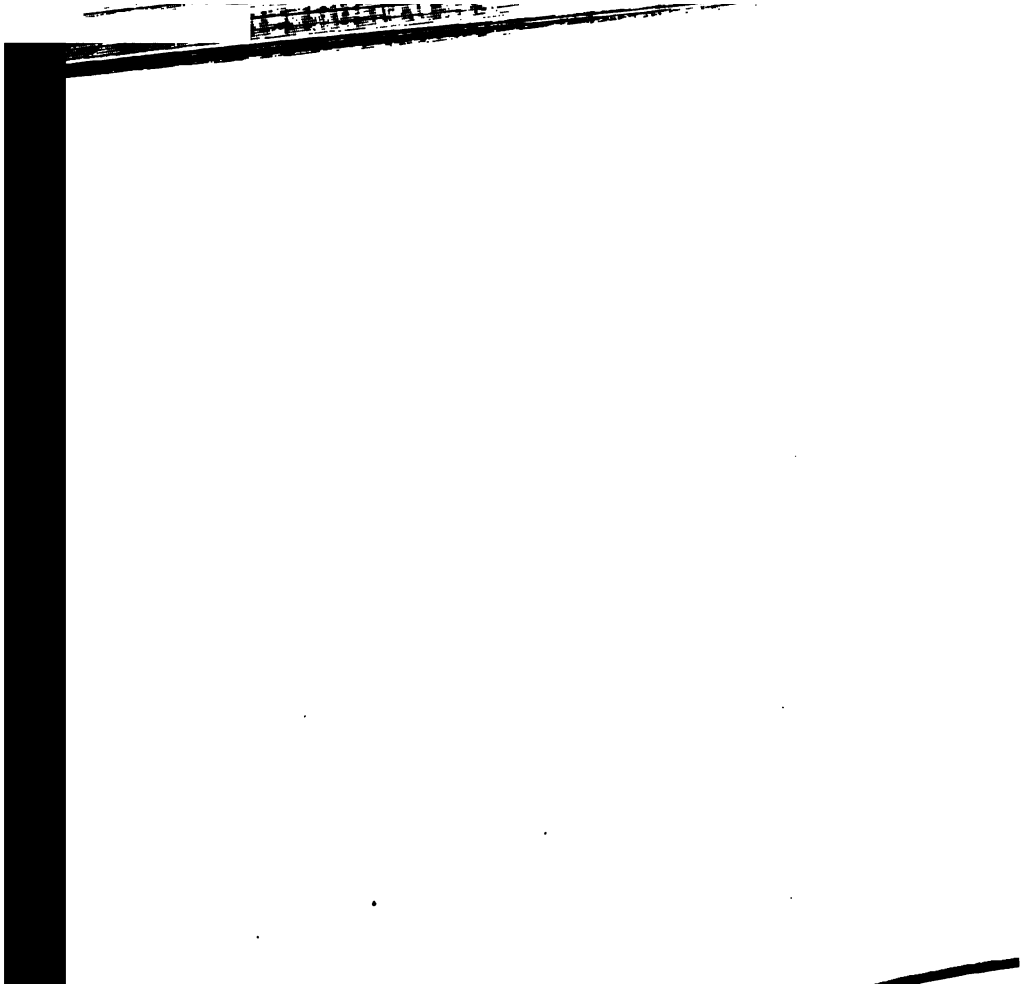
Some strata extend for hundreds of miles.

Beds are more likely to persist parallel with the coast from which the material is derived, and in any deep-sea deposits where the conditions of supply are alike.

Intergradation of beds of different materials.

Evidences of the Slow Deposition of Sedimentary Rocks.

1. Lamination of shales.
2. Evidences of objects having lain long uncovered on the sea bottom.
3. Beds formed from microscopic organic remains which commonly accumulate slowly.
4. The rate in observed cases.
   The silting up of bays, etc.
5. The wearing of pebbles of conglomerate requires time.
   Great thickness of some conglomerate beds.
6. Great conglomerate beds made by the passing of the land through a beach condition are evenly distributed.
   Example: Pottsville conglomerates of Pennsylvania.
7. The rate of denudation which supplies the materials of mechanical sediments.



[redacted]

3. Stone reefs of Pernambuco, Brazil, and western Palestine. (See p. 70.)
   Coquina of the coast of Florida.
   Æolian sandstone of Bermuda.
   Glacial gravels locally.
   Spring deposits cementing gravels.
4. Hardening of building-stone after quarrying.
5. Experimental determination by Adams and Nicolson.*

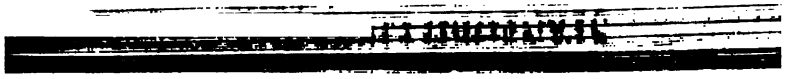
The laws of matter show that —

1. Stratified rocks must have accumulated by means of the same agencies, and under the same conditions, that govern the deposition of similar materials at the present time.
2. The oldest beds must have been laid down first, and the newer ones next on top, and so on.
3. The stratified rocks were laid down as soft sediment in an approximately horizontal position, and all changes in them, whether by consolidation, folding, faulting, or otherwise, have taken place subsequently, and are, in a sense, accidental.

UNSTRATIFIED, OR ERUPTIVE ROCKS.

Distinctions between sedimentary and igneous rocks.

SEDIMENTARY, OR STRATIFIED ROCKS.	IGNEOUS, OR UNSTRATIFIED ROCKS.
Clastic, or of fragments	Crystalline from fused state.
Bedded	Massive; different flows may have bedded appearance.



Grouping of Igneous Rocks.

Igneous rocks may be grouped

- With reference to conditions of cooling.
  - Plutonic. Those cooling under pressure at great depths. They are, or have been, deep-seated, and have been exposed here and there by erosion.
  - Volcanic.
- With reference to composition.
  - Acid, containing 60 to 75% of silica. They are light colored. Fuse with difficulty. Stiffen readily, and form glasses.
    - Granites.
    - Gneisses.
  - Basic, containing less than 60% of silica, and high percentages of fluxes, lime, soda, potash, iron, etc. They are dark colored, and
    1. Easily fusible (basalts).
    2. Medium fusibility (andesites).
    3. Difficult to fuse (trachites).

Forms of Igneous Deposits.

Ejected as local lava flows of fragmental material, they form—

1. Lava cones; angle varies with fluidity, 3° to 25°.
2. Cinder cones, 35° to 40°.

Craters are the cup-shaped mouths of volcanoes.

Origin of the cup shape.*

Lava sheets often spread over wide areas.

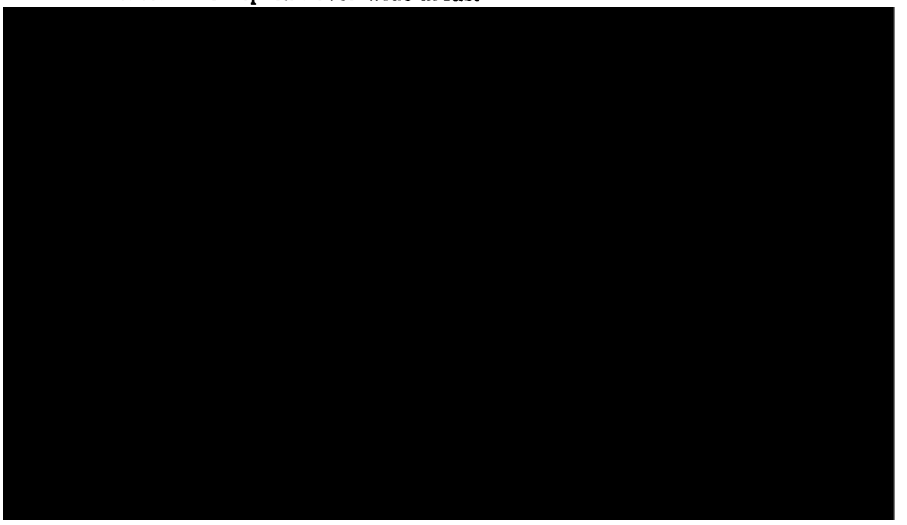


Plate XVII. — Basaltic columns, popularly known as "the Devil's post-pile," exposed on the middle fork of the San Joaquin River.

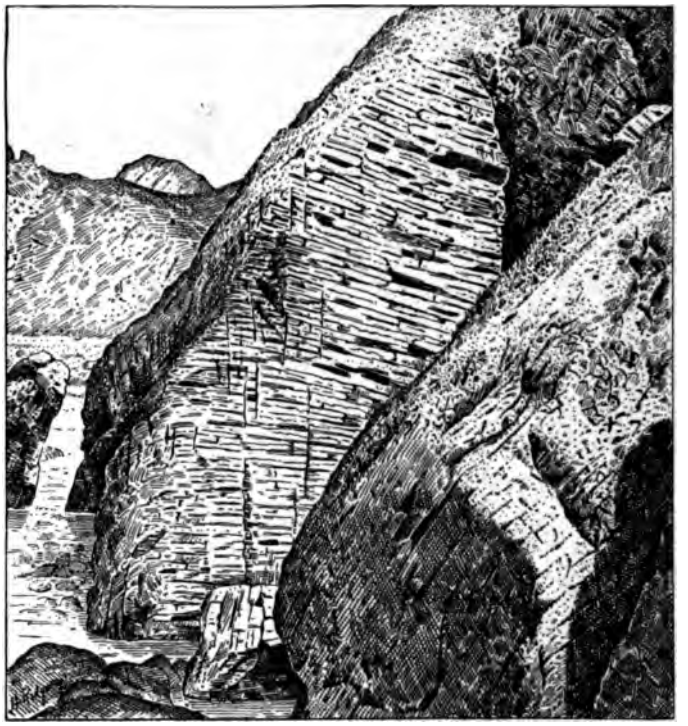
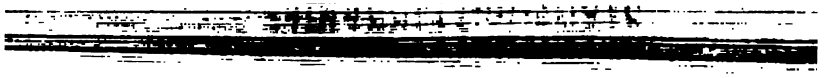


Fig. 49.—Horizontal columns of basalt exposed on the shores of Fernando de Noronha.



The position of mineral veins among economic geologic deposits will be understood from the following:

Economic geologic deposits.
1. *Organic accumulations:* coal, lignite, limestone, chalk, phosphates.
2. *Mechanical accumulations:* placer gold, diamonds, tin, magnetic iron sands.
3. *Igneous, or metamorphosed deposits:* certain building-stones, slates, some iron ores.
4. *Bedded chemical deposits:* salt, gypsum.
5. *Vein deposits or lodes.*

Veins are sheets of rocks filling fissures in other rocks.*

Difference between veins and dikes.

Dikes are crevices in the rock filled with molten rocks.
Dikes of sandstone exceptional. (See page 238.)

Veins are crevices filled with mineral deposited from solution in underground waters.†

False veins are crevices filled from above or below. (See Sandstone dikes, p. 238.)

If veins are made by minerals filling crevices and cracks in the rocks, it becomes important to understand the forms, sizes, and depths of cavities in the rocks.

Origin of crevices.

1. By torsion, or twisting of the rocks.‡
2. Earthquake jars when the rocks are under tension.
3. Faults.
4. Openings along the crests of anticlines and the bottoms of synclines when the beds are folded.
5. Shrinkage due to dolomitization and loss of water.

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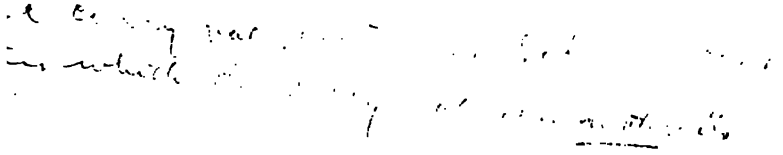


not carry [illegible] — Leaders and those
[illegible] [illegible] very valuable material.

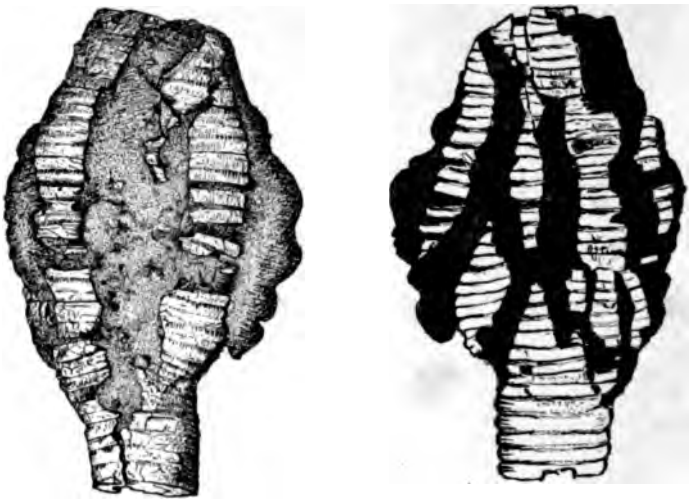


Fig. 50.—Geodes formed in the stem of a crinoid. The deposition of quartz began in the hollow stem which was finally broken asunder. Natural size.

Depth of crevices.

Rocks closely confined flow under great pressure.

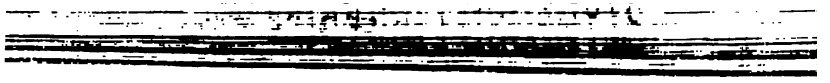
At certain depths, about six miles, crevices can not remain open.*

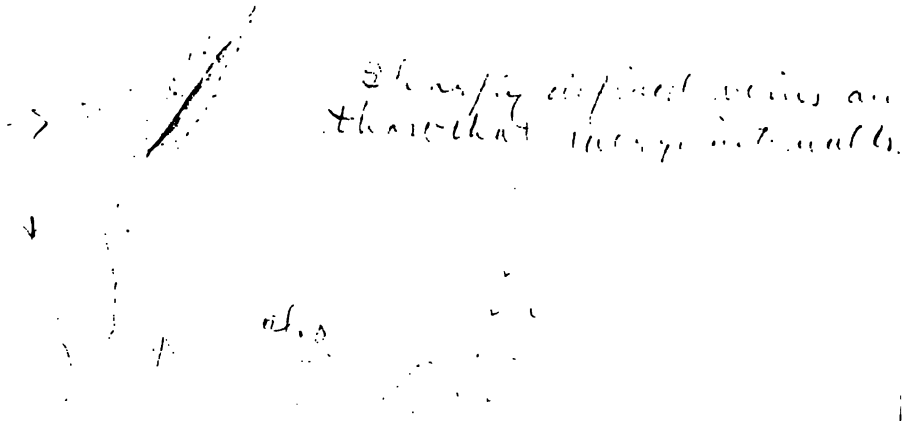
Experiments of Adams and Nicolson.†

Veins formed in open crevices must have formed within the zone of rock stability.

Thickness of veins.

Varies from a fraction of an inch to many feet.





Occurrence of veins.

Veins are more abundant in metamorphosed rocks, and in some mountain regions, because these are often the seats of dynamic action and the rearrangement of minerals.

Mineralizing agencies often more active in such regions.

The filling of veins.

Theories concerning the source of the vein materials.*

1. *From below* (Posepny, Newberry, and others).
2. *From above* (Werner and Wallace).
3. *From sides*, or lateral secretions† (Sandberger,‡ Winslow, Van Hise).

Processes of filling.

1. From volatilization, *i. e.*, from gases or fumes.
   Example: sulphur.
2. From hot waters holding minerals in solution.
   Examples: box-pipe from Comstock lode; hot springs deposits.
3. From deposits by waters containing mineral in solution at ordinary temperatures.

How minerals change in depth.§

Oxides and free gold above.
Sulphides below.

[redacted]

Uncertainties in mining for precious metals, in so far as they depend upon the extent of the ore deposits, are due to —

1. Irregularity of veins, fractures, or crevices in which the ores exist.
2. Irregularity of the conditions of deposition.
3. Irregularities due to displacements since deposition.

The *risks of mining* are due largely to these uncertainties.

If rocks were uniform in texture and composition, and if we knew the conditions and stresses under which they have been formed, the positions of the veins might be calculated.

Certainty of mining bedded deposits.

Coal, lignite, and gypsum; salt, asphaltum, etc.

South African gold beds.*

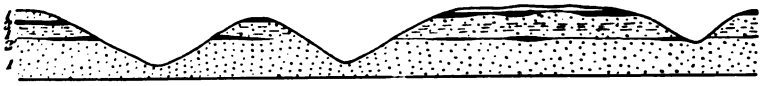
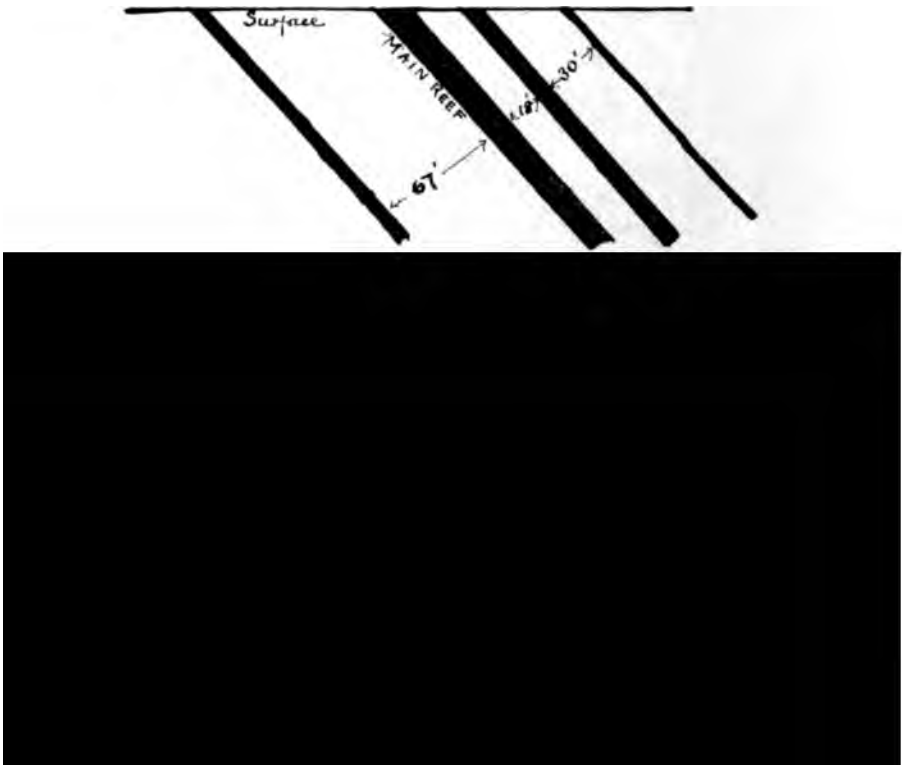
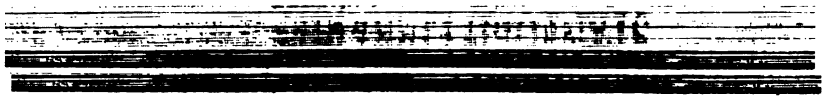


Fig. 52.—Bedded ore deposits (black) interstratified with other horizontal rocks.





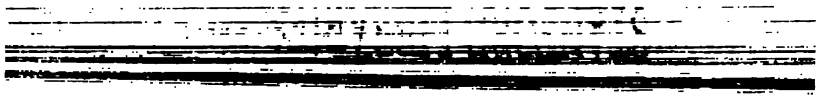
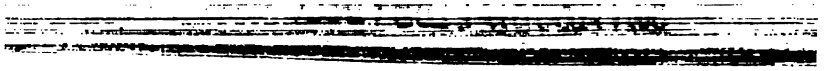


Plate XVIII.—Dolomitic limestone (dipping toward the right) with joints across the beds filled with minerals that are left in relief upon the weathered surface.



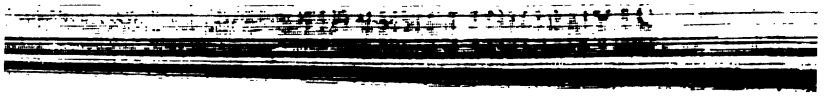
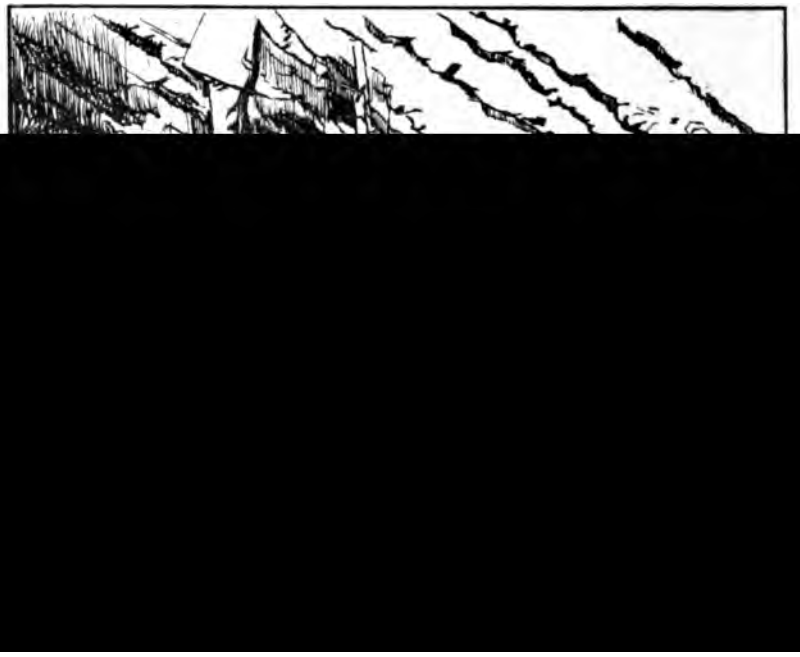
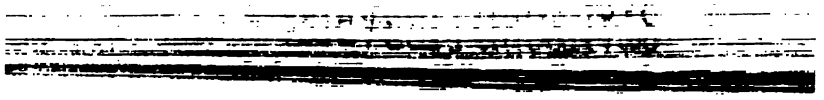


Fig. 55.—Jointed shales on the east shore of Cayuga Lake, N. Y. (Martin.)





*Sandstone dikes.**

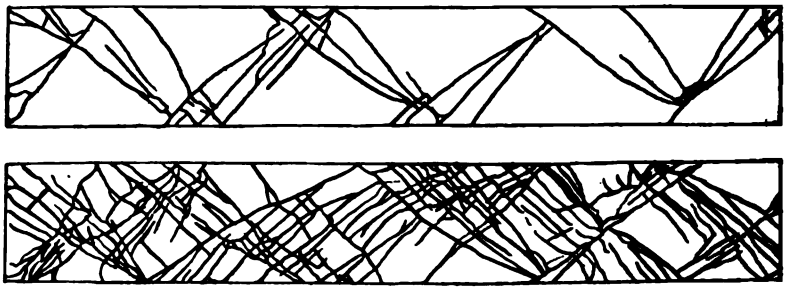
Joints or cracks in the rocks are occasionally filled with what are called sandstone dikes.

These are usually carried by water, or some other fluid, from soft sands into open crevices.

Sandstone dikes are common near Santa Cruz, and on Graves creek, San Luis Obispo county, California. (Plates XIX and XX.)

Theories of the causes of joints (other than those of basaltic columns).

1. *Contraction*, as sun-cracks in mud.
   These are not straight and clean-cut.
2. *Torsion*.
   Daubrée's experiments with ice.†
3. *Earthquakes*.
   Effect of sharp snaps on rocks under strain.
4. *Pressure*.



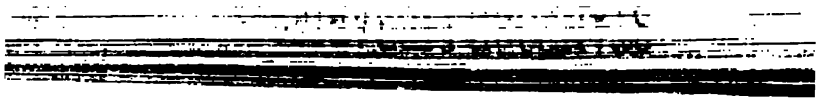
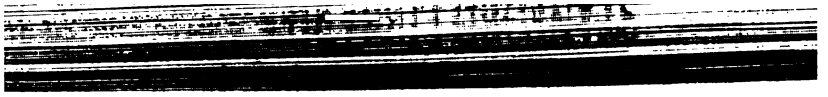


Plate XX. — A sandstone dike cutting Miocene diatomaceous shales, on the beach six miles west of Santa Cruz, California. In the foreground the dike material has been removed from the cavity by the waves. (Newsom.)



The Cleavage of Rocks.*

Cleavage is the easy splitting of rocks in parallel planes.

Kinds of cleavage peculiar to rocks.

1. *Crystalline* cleavage.
   Examples: gypsum, mica.
   Confined to crystalline forms.
2. *Bedding* is due to water sorting, and follows bedding planes; sometimes called "flagstone cleavage."
3. *Slaty cleavage.*

General facts regarding slaty cleavage.

1. It is always associated with folded and contorted beds.
2. It cuts across the bedding planes at various angles.
3. It occurs only in fine-grained rocks.
4. The included particles are parallel to the cleavage planes.

Experiments show that —

1. Iron cooling without pressure is *granular;* when drawn like wire it is *fibrous;* when rolled it has cleavage structure, or is *scaly;* that is, the granules are flattened.
2. Parallel re-arrangement of mica scales in clay after pressure.
3. Pressure on beeswax causes it to separate into folia, or scales.

These facts all suggest that *slaty cleavage is caused by pressure at right angles to the cleavage planes.*

This is borne out —

1. By finding wrinkled sand-beds in slates.
2. By the general folding of the rocks of slate regions.
3. By the deformation of fossils in the slates.
4. By the minerals in the slates all lying parallel to the cleavage.

Concretions.*

Concretions commonly occur as round or lenticular masses of various sizes, from that of a pin-head to several feet in diameter. (Plate XXI.)

How they differ from pebbles and boulders.

Due to the tendency of certain minerals in solution, or fusion, to segregate as they are deposited or crystallized.

They may occur in either igneous or sedimentary rocks.

1. Contemporaneous with, or part of, enclosing beds.
   Rogenstein, bauxite.
2. Formed subsequently.

Bedding planes sometimes pass through concretions.

Commonly formed along certain beds.

Concretions in sandstone are apt to be of lime; those in limestone are apt to be of silica.

Liable to form about bones or shells.

Loess-puppets, fantastic forms, of lime concretions in the loess.

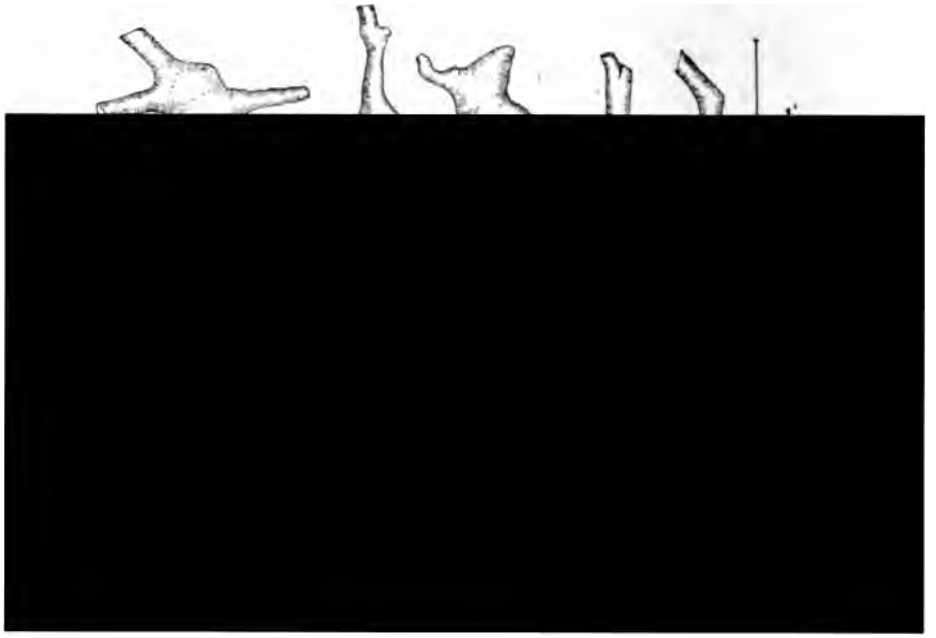
Geodes, or hollow concretions.

Geode beds of Warsaw, Illinois; Keokuk, Iowa; Indiana, etc.

Geodes may be empty or filled with calcite, dolomite, gypsum, chalcedony, quartz, zinc blende, pitch, petroleum.

Formed after the deposition of the beds.

The "iron pots," or iron geodes, of Arkansas.†



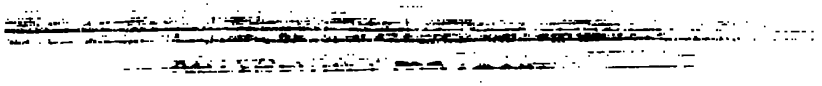
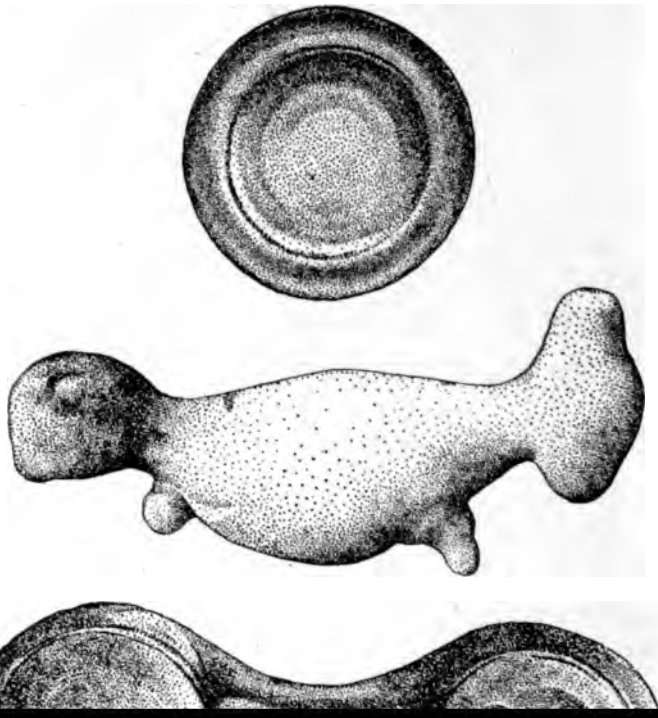


Plate XXI. — A spherical calcareous concretion from sandstone.
Piru, Ventura County, California.



*Oölites** and *pisolites* (pea-stones) are concretions of smaller size.

Formation of pisolite at Carlsbad, where it is called *rogenstein*.

Siliceous oölite from Pennsylvania.

Oölitic limestones of Indiana.

Concretionary structure in crystalline rocks.

Due to concentric arrangement of the crystals in cooling.

"*Orbicular* granite." †

Note that—

1. *Concentric staining* is not properly a concretion. It is caused by penetration of mineral-charged waters, and the oxidation or deposition of the minerals.
2. *Exfoliation*, or spheroidal weathering, produces rounded forms which are not concretions, though resembling them.‡

Stylolites, or Cone-in-Cone.§

Stylolite is a columnar, or tooth-like structure, from a fraction of an inch to three inches long, sometimes found in limestones; it is caused by pressure of the overlying beds.

Fulgurites.‖

A fulgurite is a tube one or two inches in diameter formed by lightning fusing soil or sand. It is sometimes formed in hard rock.

* Bibliography of oölites. By T. C. Hopkins. 21st ann. rep. Indiana Geol. Surv., 409–410. Indianapolis, 1897.

The Geologist, 1858, pp. 72–73. (Insect eggs as oölites.)

Nature, Nov. 12, 1896, LV, 40. (Bacterial origin of oölite.)

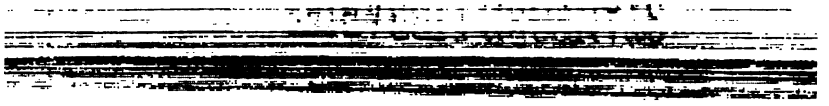
E. B. Wethered. Quar. Jour. Geol. Soc., 1891, LI, 196. (Organic origin.)

E. H. Barbour and Jos. Torrey. Am. Jour. Sci., 1890, CXL, 246–249.

G. R. Wieland. Am. Jour. Sci., 1897, CLIV, 262–264. (Pennsylvania siliceous oölites.)

Rothpletz. Am. Geol., 1892, X, 278–282.

Griswold and Agassiz. Bul. Mus. Comp. Zool., vol. 38, no. 2, pp. 29–62. (Florida oölites.)



Displacements of Rocks.

EVIDENCES OF ELEVATION AND DEPRESSION. (Plate XXII.)

1. Evidences that most sedimentary beds were deposited in the ocean.
   a. They are water-bedded.
   b. They contain remains of marine animals.
2. As they are now on land, in hills and mountains, they must have been elevated.*

But it has been shown that while the earth's surface rises in one place it is depressed at another, so that there must be a warping of the beds. This may produce *tilting*, *folding*, or *faulting*.

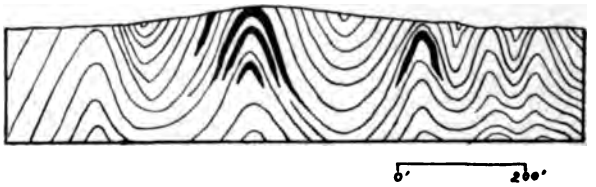


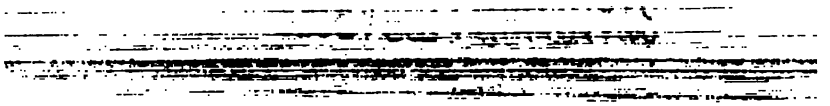
Fig. 60.—Section across the saddle reef folds at Hargreaves, New South Wales, showing the ores in the anticlines. (Watt.)

Theory of isostacy.

Isostacy refers to a state of equilibrium.

(This is discussed at length under Physiography, Part IV.)

Geologic importance of folds and



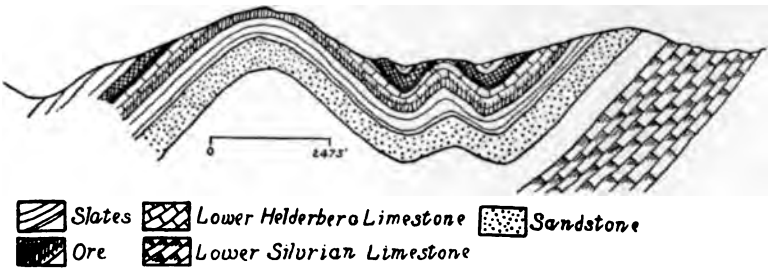
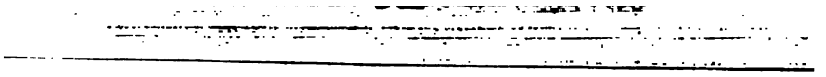
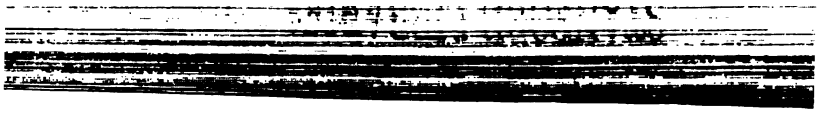


Fig. 62.—Section across the Rich Patch iron deposits of Virginia, showing the relation of the ore to the geologic structure.

Fig. 63.—Section through the Bendigo gold fields of Victoria, Australia, showing the saddle reefs in anticlines and synclines. (Schmeisser.)





2. Natural sections are exposed in cañons.
   Grand cañon of the Colorado is over 6,000 feet deep.
3. Natural sections are exposed in eroded folds and faults.
   These bring the deep-seated beds to view.

Tilting.

Recent tilting shown in the Great Lakes region by level-lines.
Tilt to the southwest.
If tilting should continue at this rate Chicago, in 500–600 years, will have occasional discharge to the Illinois river; in 1,500 years it will be continuous. At the present rate, in 3,000 years Niagara will cease to flow, and the water of the Great Lakes will discharge toward the south.*

Folding.†

One of the postulates of geology is that —

1. *Sedimentary rocks were originally laid down in approximately horizontal beds.*
   If this is true it follows that —
2. *Folds, tiltings, and faults in sedimentary rocks were made subsequently.*

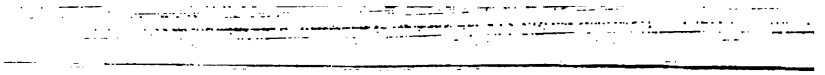
Folds are wrinkles of various sizes.

1. Broad and gentle, with axes far apart. (No. 4 in Fig. 66.)
2. Sharply crumpled.‡
   Crumpling is very marked in many schists.
3. Overturned. (Nos. 6 and 11 in Figs. 66 and 67.)
4. Radiate, or fan-shaped, as in the Alps.§

1 Sec. Bulletin de la Société Geologique de France, Quatrième Serie, Tome Dexpième.

Réunion Extraordinaire de la Société Géologique dans les Alpes-Maritimes.

Première Partie - Paris 1904



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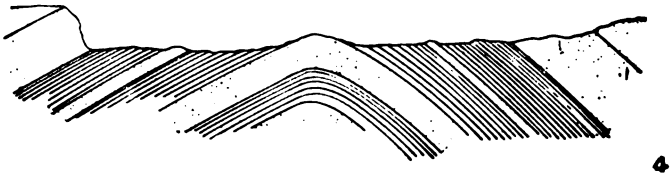

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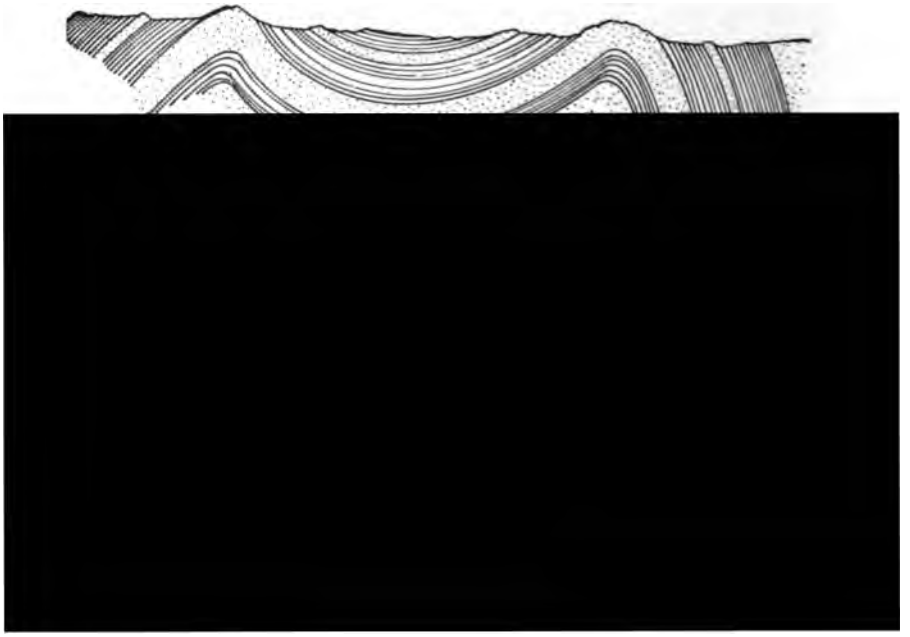
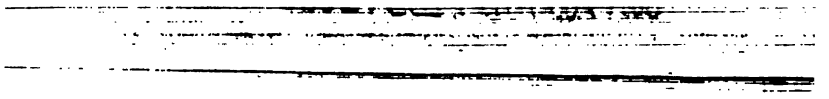




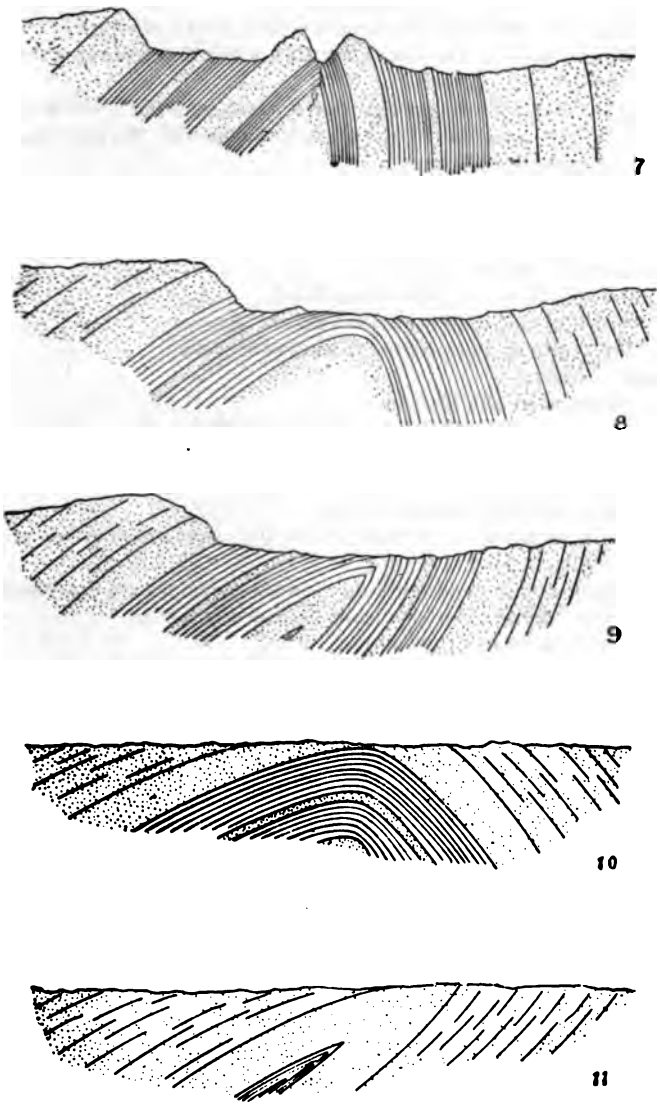


Fig. 67.—Sections across anticlines showing types of structures and topography in the Paleozoic region of southwest Arkansas. The dotted areas represent sandstones, and the shaded parts shales. (Ashley.)

Anticline.

Syncline. (Middle of No. 5. in Fig. 66.)

Monocline, or a slope in one direction (but not an overturn).

Location of axes by the use of the dips, when the exposures are many or few.

Dip is the slope of a bed of rock down which water or a ball would run.

Dip is measured by the angle it makes with the horizon, and is expressed in degrees.

Clinometer and compass.

Caution against *false-bedding.*

Caution against apparently horizontal beds.

Caution against "creep." *

Use of dip in locating beds in depth.

Width of the outcrop varies with the dip.

Use of dip in determining thickness of rocks.

Strike of rocks.

Direction on the surface.

The water-line against the face of a bed.

Use of strike in tracing beds on the surface.

Dying out of folds.

In length; the overlapping of folds.

In depth, as shown in mines, where the rocks crush or compress in depth, instead of folding.

The anticlines are elevated more than the synclines are depressed.†

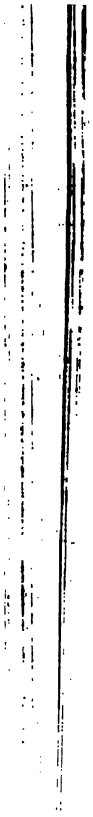
What is meant by rocks being *geologically higher.*

Not a matter of hypsometry.

How outcrops with various dips look on geological maps.

Meaning of colors on geological maps.

Appearance of synclines; of anticlines.



A TYPICAL EXAMPLE
OF THE
GEOLOGY OF NORTH ARKANSAS
LOWER CARBONIFEROUS
ORDOVICIAN
SCALE OF MILES
Elixir
Keener
Oregon
Pedlo
BOONE
Bellefonte
Powell
MARION
Rally Hill

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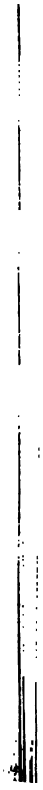


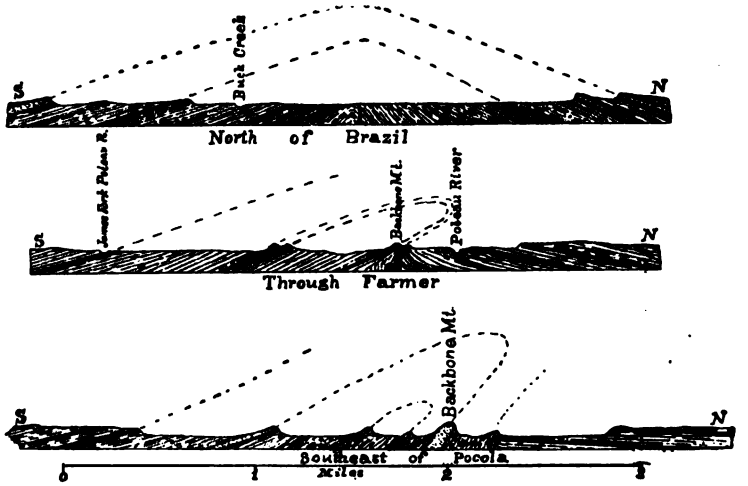


Fig. 70.—North-south sections, ten miles apart, across an anticline in the Coal Measures of Indian Territory. The section at the top is farthest west; toward the east the fold merges into a fault. (Drake.)

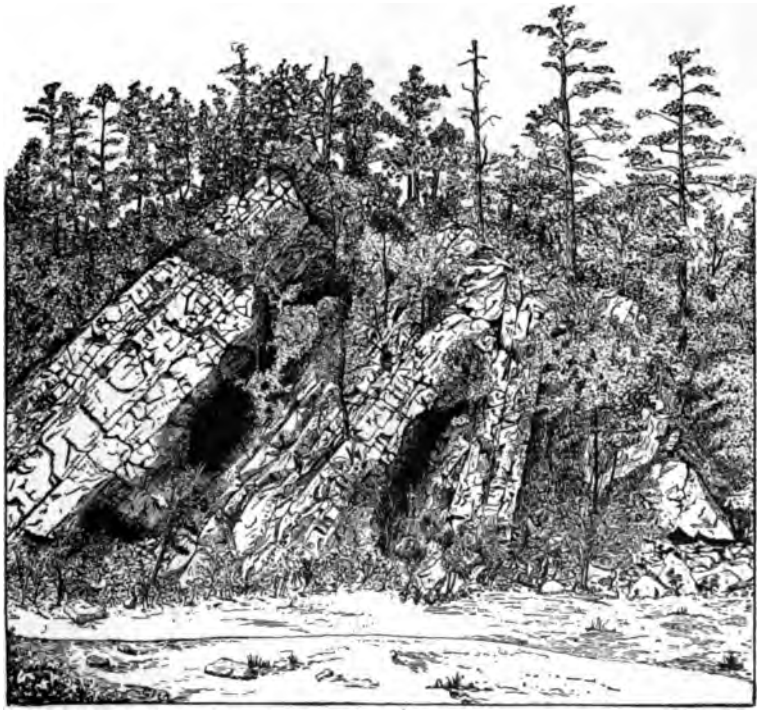


Fig. 71.—An overturned anticline. The resisting beds are sandstones. (Ashley.)

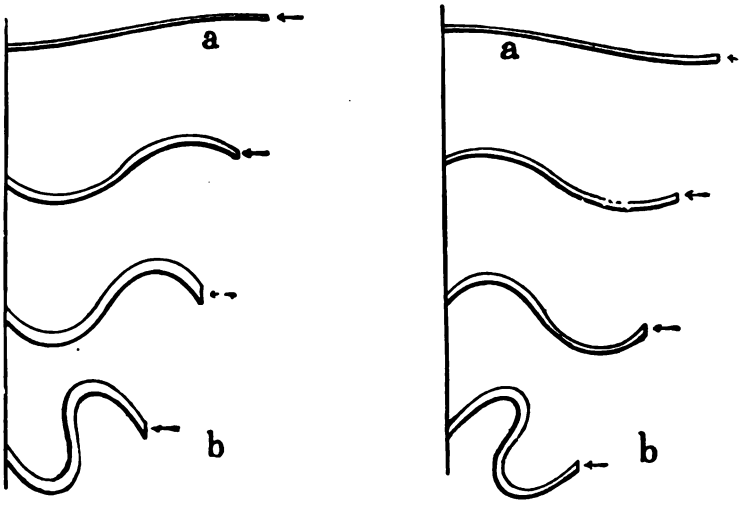
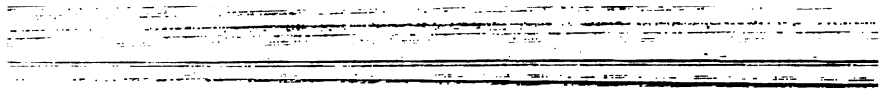


Fig. 72.—Diagrams showing the effect of original dip upon ultimate structure. (Ashley.)



*Overturns.**

Influence of original dip upon overturns.

Overthrust folds form more readily than underthrust folds, because of the easier relief being upward.†

Effects of folds on topography.

1. Anticlinal valleys.
2. Synclinal valleys.
3. Synclinal hills.

Strong structures.

4. Monoclinal hills.
5. Anticlinal hills.

Weak structures.

6. Isoclinal ridges.

FAULTS.‡

Faults are displacements of the rocks along lines of fracture.

They are of much more importance in economic geology, partly because ore deposits are often formed along faults, and partly because they frequently displace ore bodies after they have been deposited.

Faults may run in any direction.

They can only take place after the formation of the beds so faulted.

They occur singly or in sets.

These sets may cross each other at various angles.

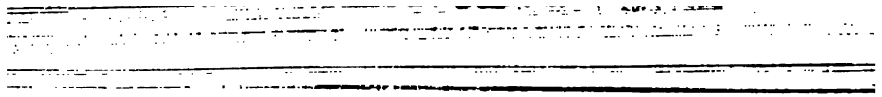
Faults are called normal, or reversed, according to the nature of the displacement.

NORMAL OR GRAVITY FAULTS.§

Produced by *tension of the beds*, allowing one side to settle.

"Faults hade to the downthrow," a rule originating in a region of normal or gravity faults, and of approximately horizontal beds.

Meaning of this expres-



Oregon lakes,* Dead Sea, and the Jordan.†
California valleys, but widened by erosion.
Deceptive thickness.

Reversed or Thrust Faults.‡

Thrust faults are caused by pressure.
Rule regarding the dip of the fault is reversed. Importance of this rule in the location of veins and beds.
Folds often merge into faults.
Sled-like turned up ends of beds on faults.

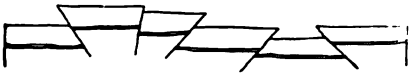


Fig. 76.—Both depression and elevation of fault blocks produced by pressure and faults dipping in different directions.

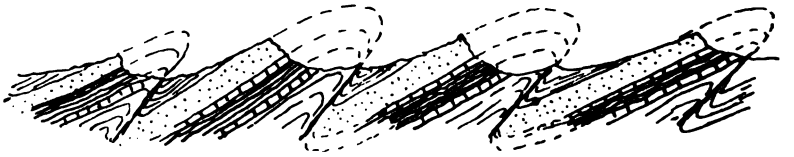
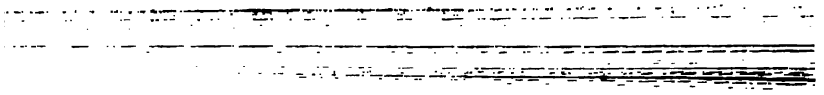


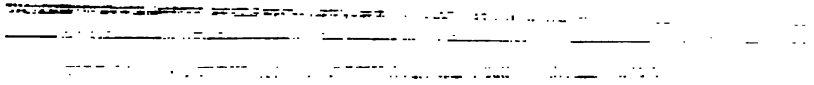
Fig. 77.—Section across folds that become faults repeating the same beds along their outcrops. (Heim and de Margerie.)

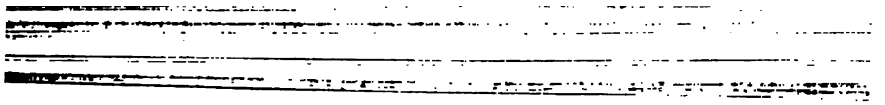
Fig. 79.—An artificial fold passing into one large and many small faults. (Willis.)

Amount of displacement in faults.

From the fraction of an inch to thousands of feet.







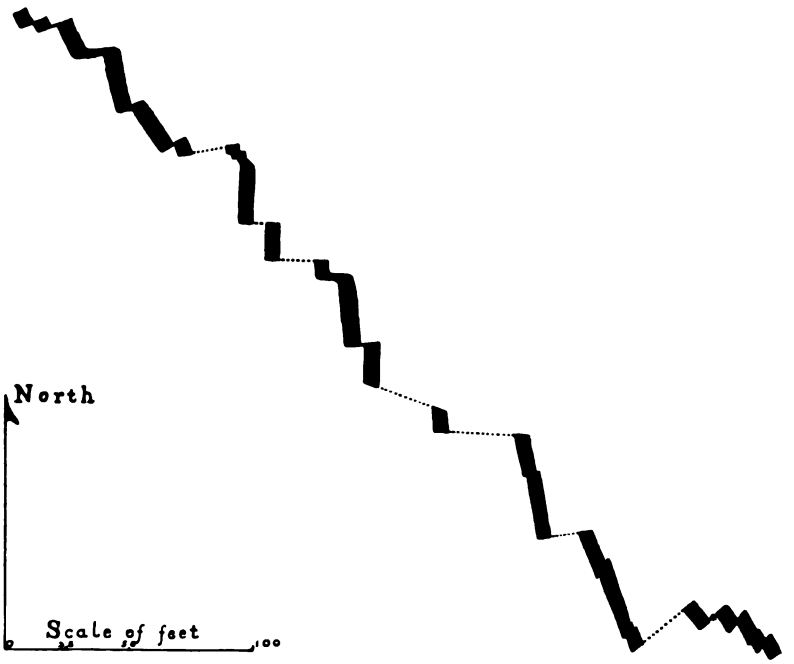
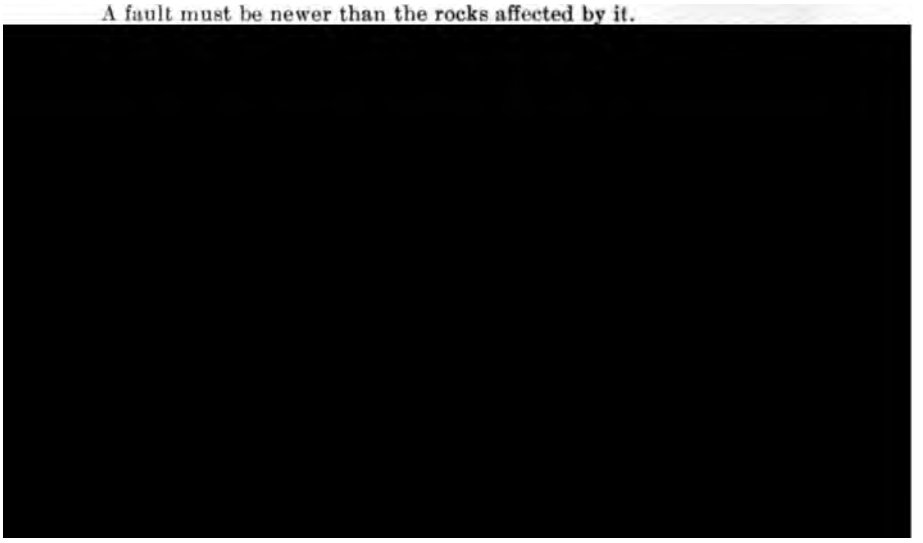


Fig. 80.—Plan of a laterally faulted calcareous stratum, San Lorenzo river, Ben Lomond, California. (Newsom.)

Ages of faults.

A fault must be newer than the rocks affected by it.



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4. By certain springs emerging on the fault-line. (See no. 2.)
5. By changes of topography.
6. By change of rock or soil on the strike of the fault.

Economic Importance of Faults.

Mineral veins are often formed in or near fault-lines.

Mineral deposits are displaced by faults.

It is therefore frequently important to determine both the direction and amount of displacement by a fault.

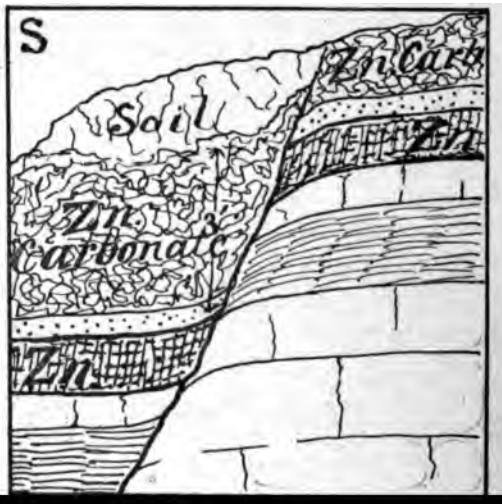
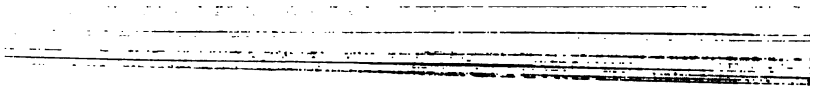


Plate XXIII. — A ledge of siliceous mineralized rock along a fault-line in the Ozark zinc regions.



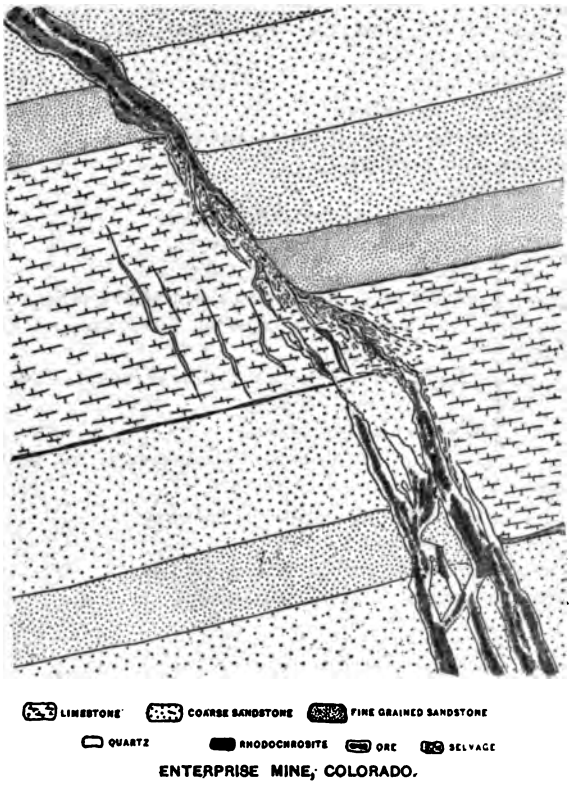


Fig. 83.—Ore deposited in a fault, Enterprise mine, Colorado. (Rickard.

The Alteration of Rocks.

Rocks do not remain the same, but are subject to changes.

Metamorphism is one of these changes.

METAMORPHISM.*

The change, whether chemical, mineralogical, or other rearrangement, that rocks undergo after their original formation or deposition.

It often obscures the —

1. Original form.
2. Method of formation.

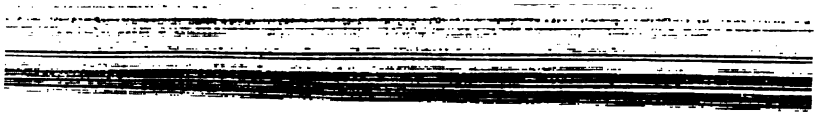
Not all changes are spoken of as metamorphism, though the distinction is sometimes quite arbitrary.

Changes other than metamorphism:

- Decay.
  Example: formation of kaolin.
- Coloration: mottling of rocks.
- Hydration. (See page 280.)
- Sandstone is sometimes changed to quartzite at the surface by a process of weathering or local metamorphism.
- Limestone and fossils of lime carbonate change to crystalline marble.
- Lignite changes to coal.
- Coal changes to anthracite, graphite, and natural coke.

Changes may be —

1. In form and texture, but not in composition.
   Aragonite to calcite.
   Clastic to crystalline rocks: grits to schists.



4. Expulsion of water and vaporizable ingredients.
5. Melting, baking.
6. Crystallization, with or without change in constituent minerals, including —
   Marmarosis.
7. Production of new minerals.
8. Production of foliation and schistosity.
9. Obliteration of fossil contents.
   The fossils are not always obliterated.*
10. Obliteration of bedding planes.

Causes of metamorphism.

1. Hot waters with CO_2 and minerals (alkalis) in solution.
2. Hot vapors and gases beneath the surface.
3. Movements in rocks, such as pressure, crushing, and shearing.†
4. Intrusion of hot eruptive rocks.

Heat and moisture are the chief agents of metamorphism.

Amount of heat.

But little heat is necessary to produce metamorphism, and there are some minerals in metamorphosed rocks that can not withstand much heat.

Amount of moisture.

But little moisture is necessary in metamorphism.

Dry heat, however, does not affect rocks far.

Certain minerals contain water.

Time an important element.

The oldest rocks are usually most metamorphosed.

How heat may be produced in rocks.

1. By chemical action.
2. By the crushing and shearing of the rocks.

A dike in chalk in County Antrim, Ireland, has altered the chalk to the following rocks, beginning next to the dike:

1. Dark-brown crystalline limestone.
2. Saccharoidal limestone.
3. Fine-grained limestone.
4. Porcelanous limestone.
5. Blue-gray limestone.
6. Yellow-white limestone.
7. Grades into chalk.

Alteration of the slates of the Sierras by granite dikes; in places the metamorphism has affected the rocks as much as a mile from the dikes.

Sedimentary beds are sometimes baked to "an intensely hard and exquisitely white porcelain" by a lava sheet.*

These changes vary greatly in degree, from incipient metamorphism to a change of the form and of the chemical composition of the rocks.

Experiments of Daubrée.†

Great changes, however, are not always produced. Near the crest of the Siskiyou Mountains, on the north side, there are many exposures in the railway cuts, showing granites containing inclusions that still preserve their bedding planes; the inclusions are of all sizes up to 20 feet or more in diameter.

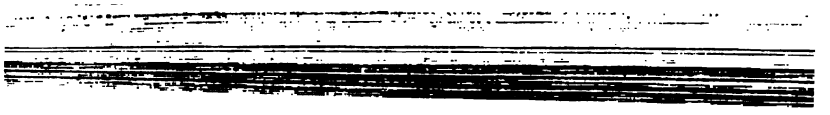
II. Regional or General Metamorphism.‡

This name is applied to wide areas where there is apparently no connection between local igneous phenomena and the metamorphism.

Of the same nature as local metamorphism, but different in extent.

Great regions of schists fall under this head.

Examples: New England, Wisconsin, Michigan, and Minnesota.

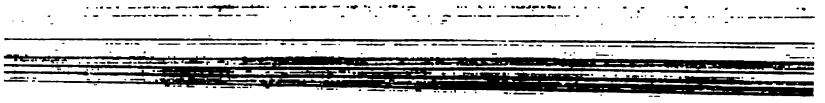


Metamorphosed Rocks.

All schists,* gneisses, some quartzites, slates, serpentines.
Why mountains often have sediments metamorphosed.
They are regions of movements, strains, slipping, etc.
Why exposed.
By erosion.
They are often old rocks.
They are commonly deep-seated rocks.

General Conclusions Regarding Metamorphism.

1. Metamorphism is the change of internal form, or structure, of either igneous or sedimentary rocks.
2. The date of the metamorphism is necessarily later than that of the making of the rocks.
3. Metamorphism is produced by —
   a. Heat.
   b. Pressure.
   c. Chemical changes aided by water and alkalis.
4. Metamorphism may be local (contact) or regional (widespread).
5. It may occur in alternate beds of a series.
6. It may affect beds either vertically or laterally.
7. Regional metamorphism is a wider extension and greater development of local metamorphism.
8. Metamorphism does not necessarily introduce new chemical elements, but may be only a rearrangement of those already present.
9. Metamorphism is seldom uniform throughout a wide area, but is often more intense here, and less so there.



Replacement.

Of woody fiber by silica. (See Plate XIV.)
Of shells, corals, etc., by silica.

Pseudomorphism.*

Dehydration, or loss of water.

Dolomitization.†

A replacement of some of the lime carbonate of limestones by magnesia.

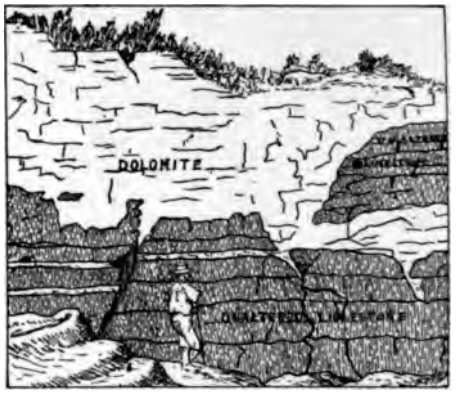


Fig. 84.—Vertical section in a quarry at Kilkenny, Ireland, showing both dolomite and unaltered limestone. (Prestwich.)

Hydration.

Anhydrite forms gypsum by taking up water.‡
Peridotite altered to serpentine.§

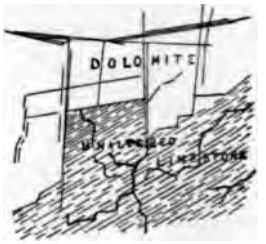
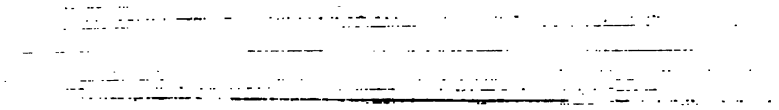


Fig. 85.—Horizontal section in

Weathering.

Changes of rocks upon exposure.‖
These changes are mostly in the direction of disintegration and decomposition, but



Underground Water in Its Relations to Geologic Structure.

Springs.

The waters of springs are meteoric waters (rain or snow) that have fallen on the earth, soaked into the ground, and are emerging naturally.*

Their emergency is caused by gravity, *guided by the rocks.*

Accumulations of water occur in rocks having room for water; that is, in porous rocks.

The porosity is due to rock structure, and *may be caused* —

1. By spaces between coarse materials.
   The coarser the materials the more the space.
   Hence, water from conglomerates and coarse sandstones.
2. By joints or cracks in rocks.
   In shales, and other compact rocks, it flows through the joints.
3. By openings caused by solution and removal of rock.
   As in the caverns of limestone regions.
   Note the size of springs in limestone regions.
4. By dolomitization which causes a shrinking of the rocks.

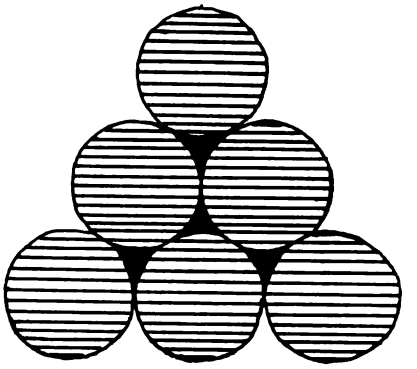
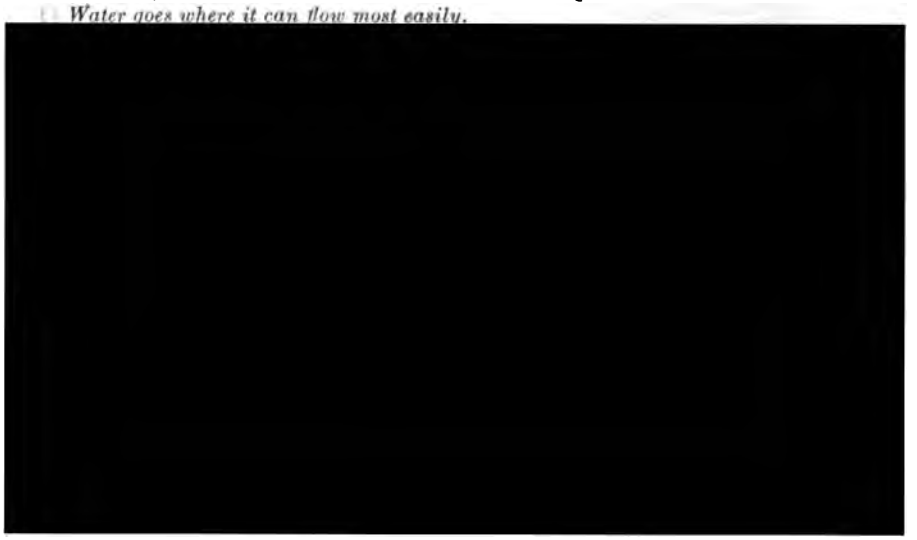
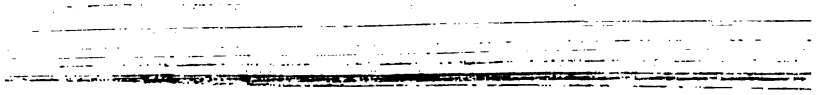
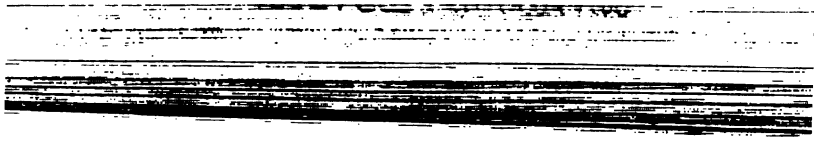


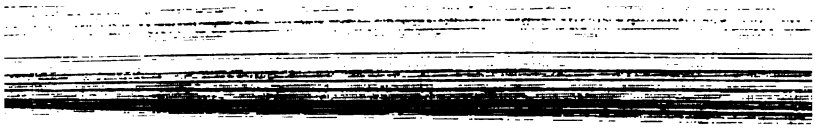
Fig. 86.—Diagram showing in black the open spaces between spheres of uniform size.

Water goes where it can flow most easily.









Wide areas are usually involved.

Essential conditions for artesian wells are —

1. Water-bearing stratum (to hold the water).
   Must be of coarse or porous material.
2. A confining stratum (to keep it in).
   Usually fine silts, especially clays.
3. Head or elevated source (to force it out at the opening).
4. Rainfall at the outcrop of the water-bearing stratum (to furnish supply).

Origin of the artesian waters of Wisconsin, Dakota, etc.

Origin of the Santa Clara county artesian waters.

Importance of determining elevations.

Help of railway levels to tie to.

Massive igneous rocks and granites have water in cracks and joints only.

The uncertainty of finding water in them due to the irregularity of joints.

*Increase of the flow of wells.**

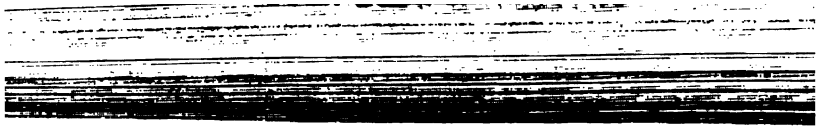
Periodic fluctuations in the discharges of artesian wells are probably due to variations of barometric pressure.

The ebbing and flowing of wells are attributed to tidal influence;† this is shown by their correspondence to be the case in some instances.

Periodic discharges may also be caused by syphon action when the shape of the water-way is favorable.

* Outbursts of springs in time of drouth. By W. E. Abbott. Jour. and Proc. Roy. Soc. N. S. Wales, 1897, XXXI, 201-206.

† H. G. Madan. Quar. Jour. Geol. Soc., Aug. 1898, LIV, 301-307.
J. F. Knightly. Geol. Mag., July 1898, p. 333.



PART III.

HISTORICAL GEOLOGY, OR PALEONTOLOGY.*

The Order of Events and Life as Recorded in the Rocks.

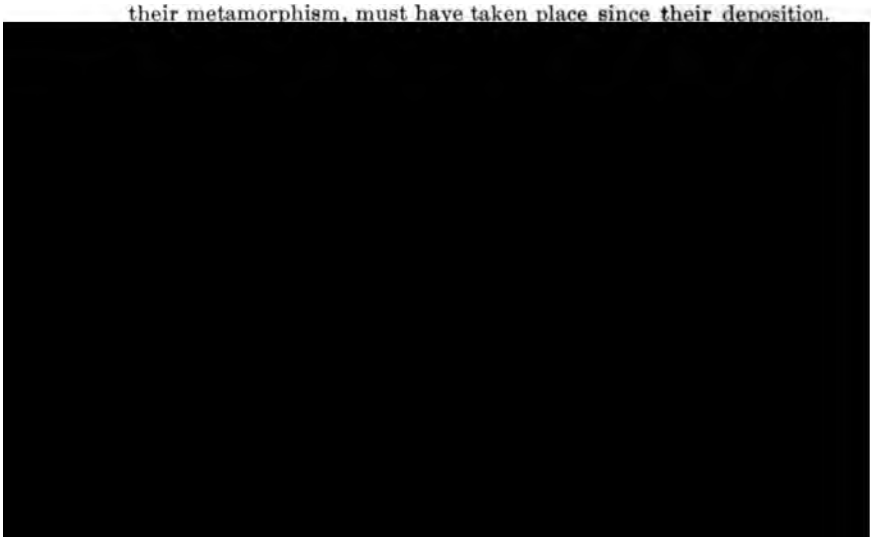
Historical Geology treats of the order and ages of the rocks — *i. e., the history of the earth as shown by the rocks and their fossil contents.*

The history of the earth must be learned —

1. By deductions from the known laws of matter.
2. By the study of the operation of these laws as shown by the rocks.

The laws of matter teach us that —

1. Stratified rocks are laid down in water (except æolian and some plant accumulations) in approximately horizontal beds.
2. The oldest beds were laid down first and at the bottom, the newest ones last and on the top.
3. The disturbance of the horizontality and continuity of these beds, and their metamorphism, must have taken place since their deposition.



9. In many places the sedimentary rocks have all been removed by erosion, and the history of the place as originally preserved in those rocks has been entirely obliterated.

It is thus evident that the earth's history, where not obliterated by erosion and metamorphism, is to be found both in the *nature and condition of the rocks, and in the character of the fossils.*

10. The geological record, therefore, is at best an imperfect one.*

What Is Shown by the Kinds of Rocks.

They are sedimentary, organic, chemical deposits, or igneous.

Changes making variation of rocks often affected life, and thus the fossil contents of the rocks.

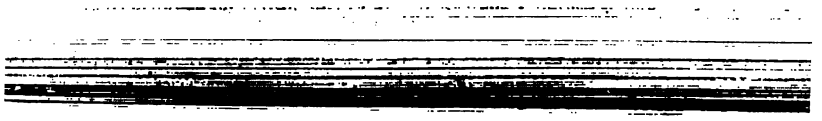
What the Present Conditions of the Rocks Show.

1. By metamorphism, that they have been affected by metamorphosing conditions.
2. By faulting, that they have been under tension or pressure.
3. By folding, that they have been squeezed.
4. By dikes, that molten rocks have broken through them.
5. By unconformities, that land conditions, admitting denudation, have intervened.

Fossils and Their Uses.†

Fossils are the remains or traces of plants or animals imbedded in the rocks. They are often called petrifactions, though they are not always petrified.

The word "fossil" was formerly applied to minerals, but it is no longer so used.



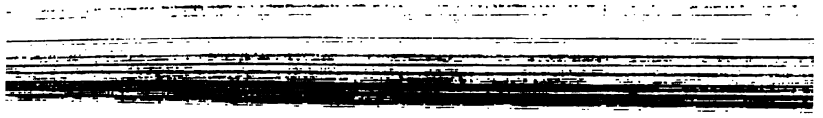
Plants may have been washed down in fresh water.
Trees and big stumps show land conditions.
Life peculiar to cold climate, indicating cold.
Life peculiar to warm climate, indicating warmth.
Changed conditions produce variation of faunas and floras.
These conditions limit the range of animals and plants on earth, and hence physical changes produced different conditions favorable to different forms of life.
In these changes many forms were crowded out and exterminated.

Marine Deposits.

Littoral.
Deep-water.
Abysmal.
Animals and plants having hard parts often have them preserved.
Examples: bones of fishes, whales, crabs, corals, shells.
Animals and plants without hard parts are seldom preserved as fossils.
Examples: jelly-fishes, slugs, soft algæ.
No remains are preserved save when the conditions are favorable.

Land Deposits.

Land animals and land plants decay for the most part, unless they fall in water or mud, or are washed to the sea and buried by sediments.
In lakes; peat-bogs; river mouths.
Things preserved in mud or clay.
Bones, skeletons, teeth, scales of fishes.
Impressions of plants, trunks, bark, and leaves; rain-prints, ripple-marks.
Wings of insects.



Land organisms have small chance of preservation.

A body was found in a copper mine in Chile that had evidently lain there since 1600 A. D., preserved by dryness and by "impregnation of the tissues by copper salts."*

Highly developed and specialized mammals are of limited range.

The Geologic Column.

All divisions are more or less artificial, for periods often grade insensibly into each other.

What is meant by "the geologic column."

The piling up of rocks upon each other.

The thickness of the beds varies greatly at different places.

Attempts to divide the column according to —

1. *Lithologic characters.*†

   Limestones, sandstones, clays; are contemporaneous and intergrade.

   Sedimentary and igneous rocks contemporaneous.

   All occur from the bottom to the top.

2. *Color.*

   "Old Red" and "New Red" abandoned.

   Color is of little importance; the same ones may occur anywhere in the column.

3. *Mineral contents*, such as coal in the Carboniferous.

   But all coal is not in the Carboniferous.

   Minerals are often introduced as veins in rocks of any age.

4. *Order in which the rocks are found.*

   This order is not everywhere the same.

2. That they are not faulted.
   This is common in some tilted regions.
   May occur in horizontal strata bringing similar beds opposite each other.
3. Look out for unconformities.
4. But conforming beds may not be continuous deposits, and intervening ones may be omitted.
   Color, texture, and mineralogic composition of bed can only be used within short distances.

*Use of fossils in the correlation of rocks.**

Beginnings of paleontology by William Smith.

*Life on the globe has been changing from the first.**

Each period has had its own forms.

This progress has involved constantly closer proximity to existing forms.

Hence, identity of fossils shows that the beds containing them have *approximately* the same age.

In every country fossils show the same general order of succession.

Why identity is only approximate.

1. Slow change of life at one place.
2. Spread of life-forms over the globe from one point.
3. Life-zones due to climatic differences.
4. Life-zones due to depth and character of water.

Use of fossils in the study of geographic changes.

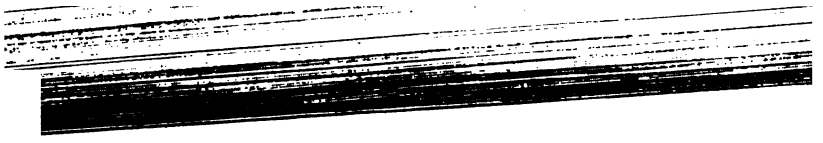
Former connection of America with Asia.

Fossils as evidences of climatic changes.

Conditions of coral growth and the distribution of fossil corals.

Fossil palms found in cold climates.

Uses of the knowledge of fossils in mining geology.



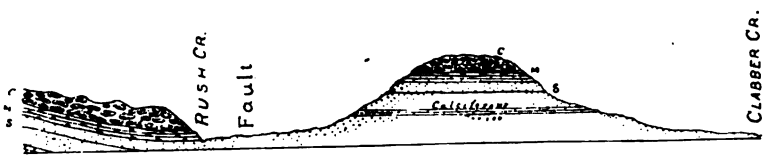
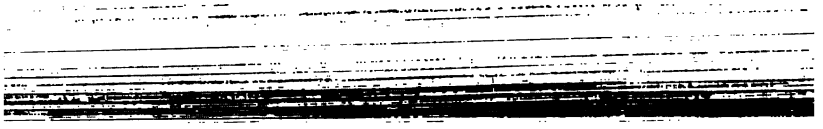


Fig. 89.—Section across a fault in the Ozark Mountains. The sandstones at *S* are let down until they appear to be continuous with the older ones below the Calciferous strata.

Characteristic Life	Period		
Man	Psycho-zoic	Recent	
Mammals	Cenozoic or Kainezoic	Pleistocene	Terrace Champlain Glacial
		Tertiary	Pliocene } Neocene Miocene } Eocene
Reptiles	Mesozoic	Cretaceous	Upper Lower
		Jurassic	Upper Middle Lower
		Triassic	Upper Middle Lower
Acrogens Amphibians		Carboniferous	Permian
			Coal Measures
			Lower Carboniferous
Fishes		Devonian	Catskill Chemung Hamilton Corniferous Oriskany
		Silurian	Lower Helderberg

[redacted]



ARCHÆAN PERIOD.

Sometimes called Azoic and Agnotozoic.

Archæan time may be divided into three periods, or eras.

1. Era of the molten globe.*
2. Era of the cooling crust: condensed vapors covered the earth with waters.

   If any part of the crust remained above water, erosion began.
3. Temperature lowered to a point admitting the simplest forms of vegetation.

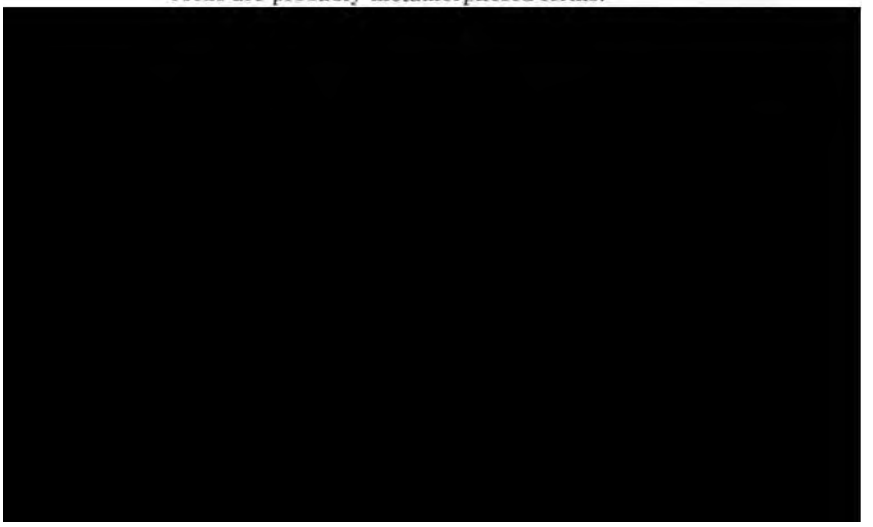
   This was the beginning of life on the earth.

The rocks formed during Archæan time are the lowest ones accessible to us, and underlie all others.

Evidences of life in Archæan rocks.

No fossils are found in Archæan rocks, but it seems reasonable to suppose that life began during Archæan time, for the following reasons:

1. Evidences of life are abundant in the next higher rocks — the Belt and the Cambrian; it is, therefore, reasonable to suppose that life had its beginning somewhat earlier.
2. Limestones (marbles) in the Archæan; probably of organic origin.
3. Iron ores abundant in Archæan; accumulated through the agency of organisms and organic acids in bogs, lakes, and meadows.†
4. Graphite and plumbago in Archæan rocks believed to be derived from plants.‡
5. Apatite is a phosphatic rock. Other forms of phosphate rocks are of organic origin, and the apatite deposits abundant in Archæan rocks are probably metamorphosed forms.



PALEOZOIC PERIOD.

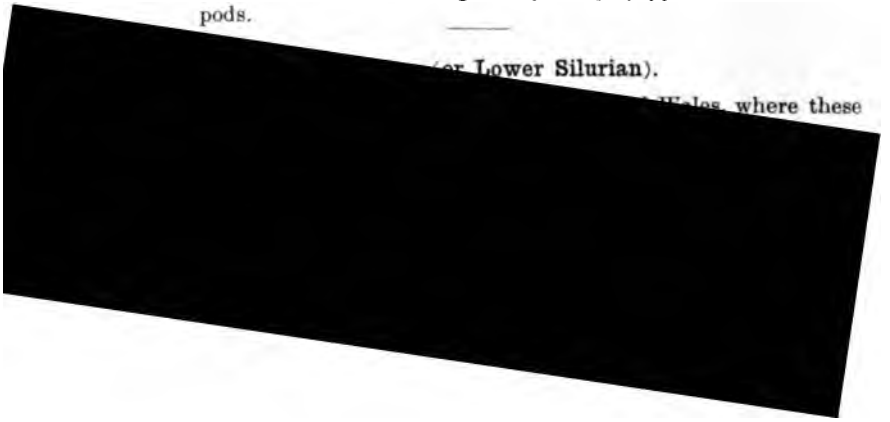
Nature of the paleozoic rocks.
Mostly marine sediments.
Some fresh-water and land deposits.
Life of the paleozoic times.
Chiefly marine invertebrates, and
Cryptogamic plants (ferns, club-mosses, horse-tails).
Paleozoic rocks are divided (beginning below) into: Belt, Cambrian, Ordovician (or Lower Silurian), Silurian (or Upper Silurian), Devonian, and Carboniferous.

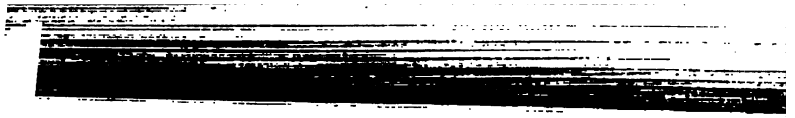
Belt.

The word "Belt" is from the Belt mountains of Montana, where the rocks of this series occur.
Until recently the Cambrian rocks were considered to be the lowest and oldest containing recognizable fossils, but in 1898 Dr. C. D. Walcott announced the discovery of the Belt series* in Montana.
The series of sedimentary beds is about 12,000 feet thick, and is unconformably below the Cambrian.
It is composed of several distinct formations. The remains of crustaceans and annelid trails occur 7,000 feet below the unconformity.

Cambrian.

The word derived from "Cambria," the ancient name of Wales, where these rocks were first studied.
Fossils.
No plants certainly known; by inference, they must have existed, to supply food to the abundant animal life.
Animals include, principally: sponges, hydrozoa (graptolites), worms, echinoderms, trilobites, gasteropods, pelycypods, and brachiopods.





Corals rather abundant.
Centipedes, the first known land animals.
Bivalves and gasteropods increase greatly in size and number.
Cephalopods appeared in the Cambrian, but are abundant in the Ordovician.

Economic products.

Lead ore of the Galena limestone of Wisconsin, Iowa, and Illinois.
Petroleum and gas from the Trenton limestone of Ohio and Indiana.
Relation of the "Trenton rock" to these products.
Marbles of Vermont, Massachusetts, New York, and Tennessee.

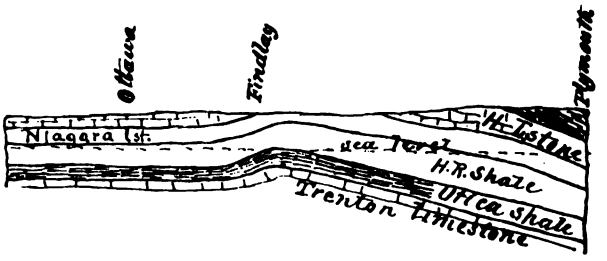
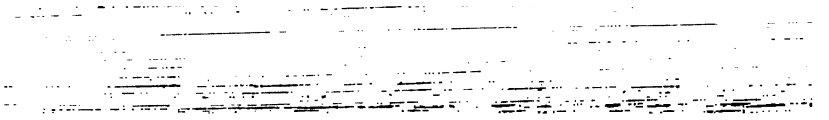


Fig. 90.—Section showing the geologic structure in the oil and gas fields of Ohio. (Orton.)

Silurian (or Upper Silurian).

Silurian rocks in North America are thicker along the Appalachian mountains, and thin out toward the west.

An inland sea with its eastern margin near the eastern border of the conti-



Economic products.

Clinton red fossil iron ore along Appalachian mountains from New York to Alabama.

Joliet building-stone of Illinois.

The brines and rock-salt of New York and Canada from the *Salina*, or salt group, of the Silurian.

Gypsum accompanies the salt, used as fertilizer or "land plaster."

Hydraulic cement, the "Rosendale," made near Rondout, N. Y.

Devonian.*

Name from county Devon, in England.

Distribution of Devonian rocks in North America.

Geographic interpretation of this distribution.

The rocks are sandstones, or shales, in New York and the Appalachians, but limestones in Ohio and Illinois.

Thins out westward.

Fossils.

Brachiopods the most abundant fossils.

Corals very large and abundant; reef forming.

Vegetation very abundant.

Fishes remarkable for numbers and size.

Some Ohio fishes 18 feet long, 6 feet across head, and 3 feet through.

Graptolites and cystids nearly extinct.

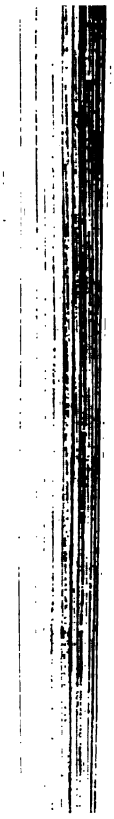
First amphibians.†

Economic products.

Oil and gas of Pennsylvania and New York.

Flagstones.

Phosphates of Tennessee and Arkansas.



Fossils.

Crinoids very abundant; some rocks almost made up of the broken stems.

Corals and brachiopods abundant.

Bryozoa; *Archimedes*.

Some amphibians.

Trilobites decline.

Economic products.

Salt brines, Michigan.

Marble of Tennessee and Arkansas.

Building-stones of Indiana.*

Coal Measures, or Carboniferous Proper.

Rocks are conglomerates, sandstones, shales, and coal.

These rocks have a total thickness of 16,000 feet in Nova Scotia; 23,780 feet in Arkansas.

No definite order of arrangement over the whole area, but locally the order is constant.

Examples: Pottsville conglomerate and Mauch Chunk red shale in Pennsylvania.

Extent of the Coal Measures in North America.

The abundance of coal, and of fossil plants, show that the land was covered by extensive marshes for long periods.

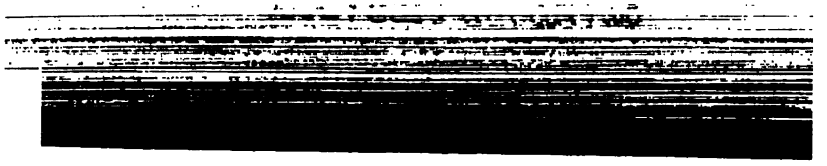
The occurence of marine fossils, interstratified with coal beds, shows that the land occasionally sank beneath the sea.

The carbon in the coal is derived from the atmosphere.

Atmosphere not necessarily heavily charged.†

Carbon from rocks constantly renewing it.

Fossils.



Permian.

Named from the province of Perm, Russia.
The division between the Carboniferous and Permian is not strongly marked in North America.
Distribution of the rocks in North America.
Retreat and shallowing of the Carboniferous seas.
The existence of beds of salt in southwest Kansas shows that an arm of the sea was there cut off and dried up.
The structure and distribution of the rocks show that there were great geographic changes in North America at the end of the Permian.

Fossils.

Crinoids much less abundant than in the Carboniferous.
The few trilobites of the Permian disappear at the end of this period.
First appearance of reptiles.

Economic products.

Gypsum and salt in Kansas.

MESOZOIC PERIOD.

The mediæval period of the earth's history.
The precise measurement of the length of the periods is not possible.
The Mesozoic is divided into Triassic, Jurassic, and Cretaceous.

Triassic.*

Cystids and blastoids had disappeared.
Brachiopods had greatly declined.
Pelycypods much more abundant than before.
Cephalopods greatly increased in numbers.
Amphibia reached their greatest importance.
Reptiles much more abundant.
First appearance of mammals.

Economic products.

Gypsum and salt of the interior basin in Kansas.
Coal beds of Virginia.
Brownstone, so extensively used in eastern cities for buildings.
Potomac marble of the Capitol columns at Washington.

Jurassic.

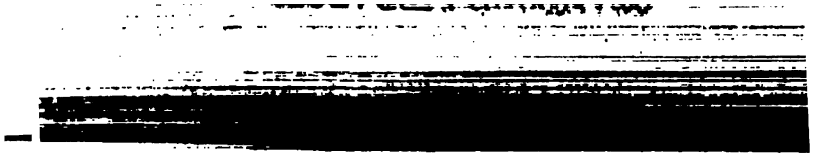
The name from the Jura mountains in Switzerland, which are of these rocks.
No Jurassic rocks known in eastern North America.
A mediterranean sea, or salt lake, in the Rocky mountains and Great Basin region.
Marine deposits of California and Oregon.

Fossils.

Cephalopods culminate in the Jurassic.
Reptiles were very abundant; some of them winged; many of enormous size.
Earliest birds known; toothed birds.

Economic products.

The gold veins of the Pacific slope are largely in Jurassic slates. These veins are not Jurassic in age, but were formed subsequently.



Economic products.

Greensand marls and potters' clays of New Jersey.
Chalk deposits of Arkansas and Texas.
Gypsum beds of Iowa.*
Coal deposits of Puget Sound, Colorado, Utah, Wyoming, Montana, and New Mexico.
In Colorado these coals are changed to anthracite.
Auriferous conglomerates in northern California.

CENOZOIC PERIOD.

The Cenozoic rocks are known as Tertiary, and Quaternary, or Pleistocene. Mammals became the most important animals.

Tertiary.

Origin of the name: Paleozoic rocks formerly known as Primary; Mesozoic as Secondary; later ones as Tertiary.
Name retained, though not used in its original sense.
Divisions of the Tertiary: Eocene, Miocene, Pliocene.
Of living shells { 50% to 90% are Pliocene. / 30% are Miocene. / 5% to 10% are Eocene. }
Distribution of the seas on the Atlantic and Pacific coasts; the interior basins.

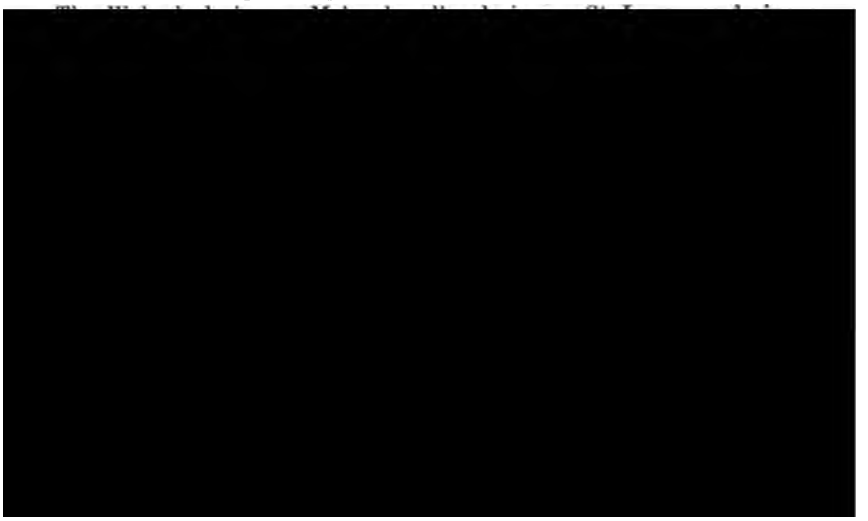
Economic products.

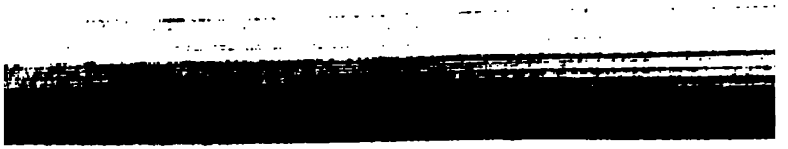
Auriferous gravels of the Sierras.
Diatomaceous earths of California and of Richmond, Va.
Phosphate rocks of Florida and of South Carolina.
Lignite of Arkansas, Texas, Mississippi, California, and Alaska.
Iron ores.
Petroleum in California.
Greensand marls and potters' clay of the South.

PSYCHOZOIC PERIOD.

Pleistocene, or Quaternary.

Man appeared during this period, or possibly even earlier.*
Association with extinct mammals.
The period was chiefly characterized by glaciers that covered a large part of northern Europe and the northern part of North America.
Climate not necessarily very much colder; decrease of 5° in Europe would bring the glaciers of the Alps down to Geneva.
Centers of distribution of ice.
Area covered at the greatest development of the ice. (See Fig. 24, p. 92.)
Evidences of glaciation; direction of movements.
Thickness of the ice.
Withdrawal of the ice.
Evidences of interglacial epochs.





Primitive Man.*

Man probably originated in the tropics, where the climate is not severe, where fruits, nuts, and berries are to be found all the year round: and on the seashore, where fish, mollusks, and crustaceans may be had at all times for food.

Deductions from zoology concerning man's character and appearance are matters of inference.

Geologic evidences found in the rocks consist of —

1. Works preserved.
2. Skeletal remains preserved.

Nature of evidence of preserved foot-prints.

On Carboniferous rocks on the Ohio river.

On limestone at St. Louis, Mo.

At Potteville, Pa.:

On lava in Central America.

Human Relics.

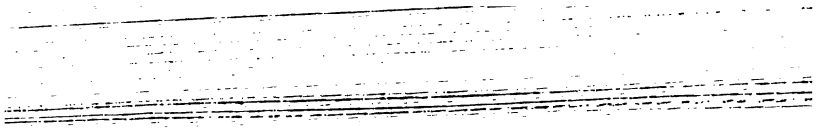
It is to be expected that the oldest traces of man are in the form of remains, for the earliest men probably had no works of art.

Character of the relics.

1. Flint implements: arrow-heads, knives, spears, chips.
   Rejects.
   Cache forms.
   Specialized forms.
   Methods of manufacture.
   Quarries.*
2. Stone axes, pestles, mortars.
3. Carvings on bones and rocks.

Where these relics are found.

1. In caverns.
   - Engis skull and bones, found beneath stalagmitic crust in cave near Liège, Belgium, associated with those of extinct animals.
   - Neanderthal skull, in cave near Düsseldorf; probably exceptional in character.
   - In southwest France in cave with drawings of mammoth, etc.
2. In peat-bogs.
   - Preservative action of the peat.
3. In river and lake beds.
   - Draining of Haarlem lake 40 years ago; relics were found.
   - The Calaveras skull in the auriferous gravels of California.*
   - A human skull said to have been found under the lava cap of Table Mountain.
   - Many human relics are reported from the auriferous gravels of California.
4. In the glacial drift and loess.
   - In Europe man preceded the glacial epoch.†
   - Evidence of his relations to the glacial epoch in North America is as yet somewhat doubtful.‡
5. Shell heaps.
   - Mounds of waste or kitchen-midden.
   - Sites of ancient settlements.
   - Castro mound; similar heaps abundant in the Santa Clara valley and on the coast.
6. Burial mounds or cemeteries.
   - Marajo burial mounds at the mouth of the Amazon, and the pottery from them.
   - The ornaments developed by primitive man.§



Length of Geologic Time.*

Difficulty of stating geologic time in years.

Rate of the recession of waterfalls.

Age attributed to the Falls of St. Anthony, Minnesota.

Method of computation.†

Efforts to compute the age of the Niagara gorge.‡

Uncertain elements in the computation.

Varying thickness of the beds.

Different heights of the falls.

Different amounts and varying character of the water.

Rate of weathering of cliffs.§

Rate of erosion and deposition.

Rate of erosion over the —

Mississippi basin	is	1	foot	for	6,000 years.
Ganges	"	"	"		2,358 "
Hoang-Ho	"	"	"		1,464 "
Rhone	"	"	"		1,526 "
Danube	"	"	"		6,846 "
Po	"	"	"		729 "
Mean rate of the six	"	"			3,000 "

Ratio of sea-bottom to land is 145 to 52, or say 2.8 times as much water as land.

The deposition of one foot of sediment would require 8,652 years.

The whole of the sedimentary beds since Archæan would, *at this rate*, require 130 millions of years.‖

Rate of cooling.¶

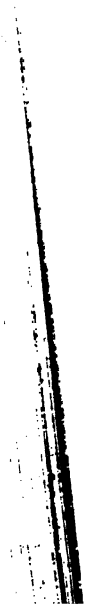
Calculated from the rate of cooling rock, the age of the earth is esti-

Rate of growth of corals and limestones.

Estimates from the rate of deposition of limestones, etc., lead Mr. Goodchild to estimate the age of the earth since the beginning of Cambrian time at 704 millions of years.

The estimates of the age of the earth since it was in a molten condition, stated in years, vary all the way from 3 million to 2,400 million years.

"Time is as long as space is broad."



PART IV.

PHYSIOGRAPHY, OR TOPOGRAPHIC GEOLOGY.*

Topographic Geology treats of the surface features of the earth in their relations to geology.

Topographic forms are produced by constructive, destructive, and modifying agencies acting upon the rocks of the earth's crust. The forms may be classed as —

1. *The major relief, or the continental masses and ocean basins.*
2. *The minor relief, or the details of the topography.*

THE MAJOR RELIEF.

The broad continental and oceanic features of the earth are due to vertical movements of large areas.

These movements are very gradual.

Theories of the causes of mass movements.

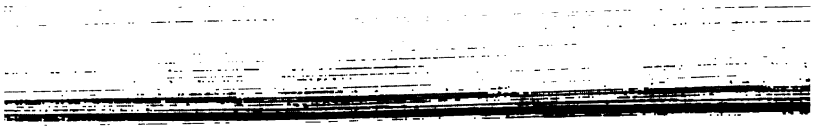
1. Loading and unloading.

The theory of isostacy.†

Adjustments must be slow.‡

* The physiography of the United States. By Powell, Shaler, Russell, etc. New York, 1897.

Physiographic types. By Henry Gannett. Folio I, Physiography. Topographic Atlas



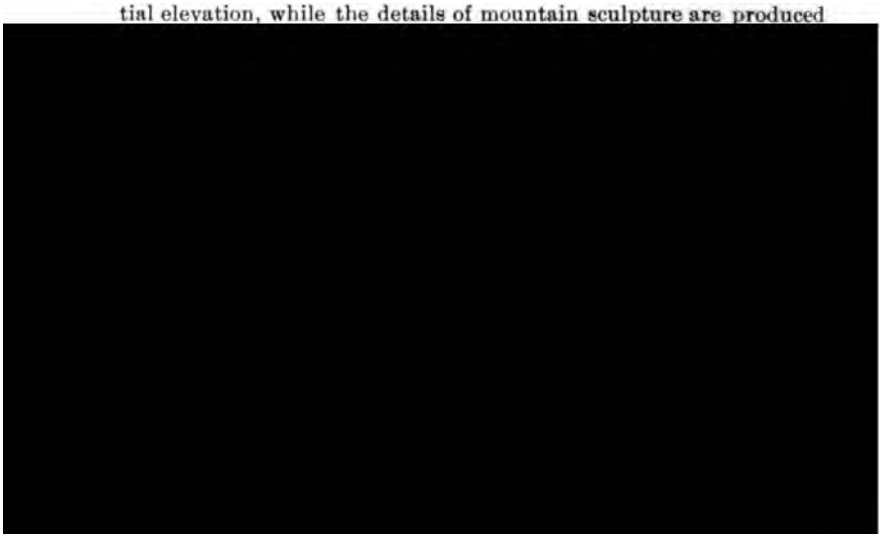
2. Unequal contraction of the globe.
   Theory of the early cooling of the plateaus.
   Deeper cooling along depressions.
   Theory of differences of materials.
      Daubrée's experiments with rubber.*
3. Early tidal action.
   Tendency for early folds to be permanent.

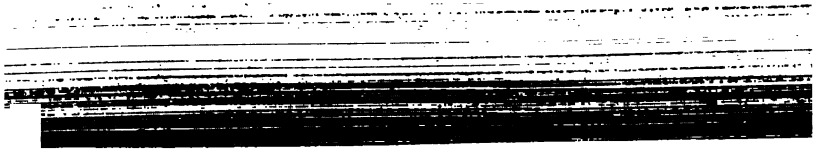
Ocean Basins.

Relations of ocean basins to the life of the globe.†
Relations to land areas.
Modification.
   By deposition —
      1. Of mechanical sediments.‡
      2. Of organic sediments.
      3. Of eruptive materials.
   By elevation and depression.
Probable instability of continents and ocean basins.
   Suggested by faunal migrations.
   Suggested by elevation of marine sediments, which is as great as the depths of the oceans.§

Mountains.‖

The great masses of mountain systems are due to deformation or differential elevation, while the details of mountain sculpture are produced





Mountain Chains.

Theories of the origin of mountain chains.*

1. Arching of the rocks. (Deformation.)†
2. Rise of isogeotherms through sediments.
3. Outflows of lava.
   a. Due to relief of pressure by arching.
   b. Due to relief by tensile movements.
   The fusion point is lowered in both cases.
4. Permanency of folds, however produced.
5. Faults.
   Location of faults of California with reference to the Sierras and Coast ranges.‡ (See Plate XXV.)

Isolated Peaks.

1. Culminating points in mountain chains.
2. Constructed by volcanic ejectamenta.
   San Francisco mountains; Flagstaff, Arizona.
   Jorullo, Mexico, made in a night (1,692 feet).§
3. Mountains or peaks left by circumdenudation.
   Enchanted mesa and the buttes of that type.
   (See also page 48 and Plate XXIV.)

MINOR RELIEF.

Relief forms may be built up by construction, may be produced by some modification or superinduced structure, or they may be the results

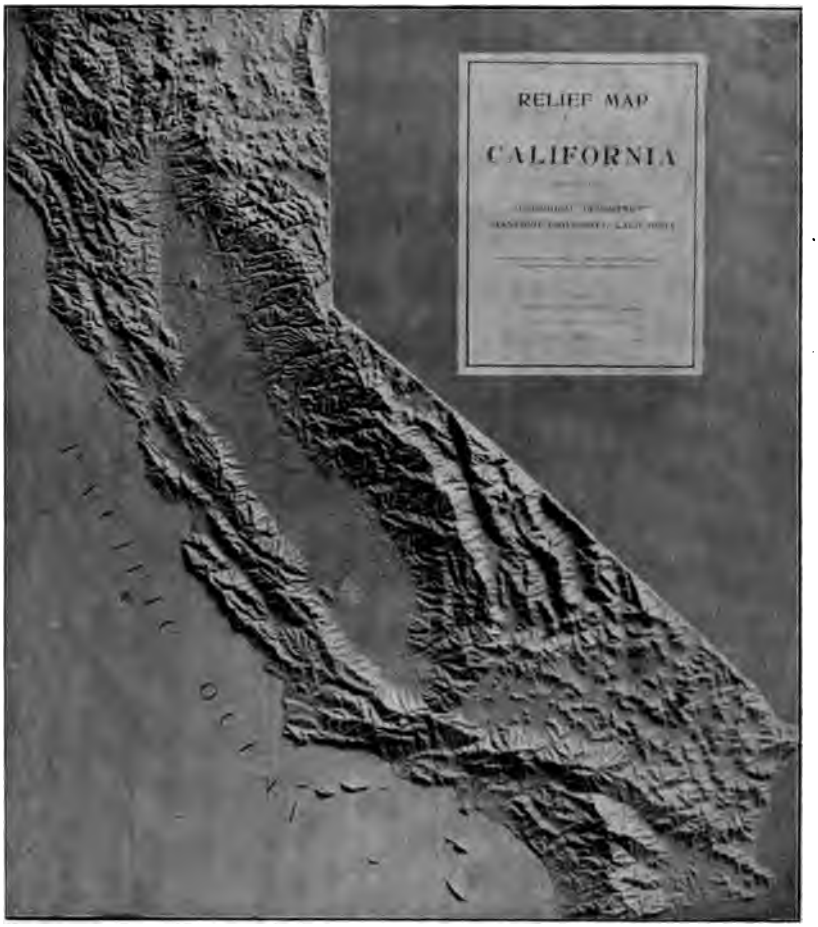
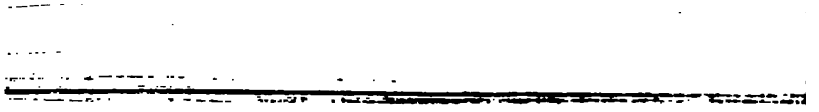


Plate XXV. — Photograph of Dr. Drake's relief map of the State of California, showing the northwest–southeast axes of the valleys, partly due to faulting.



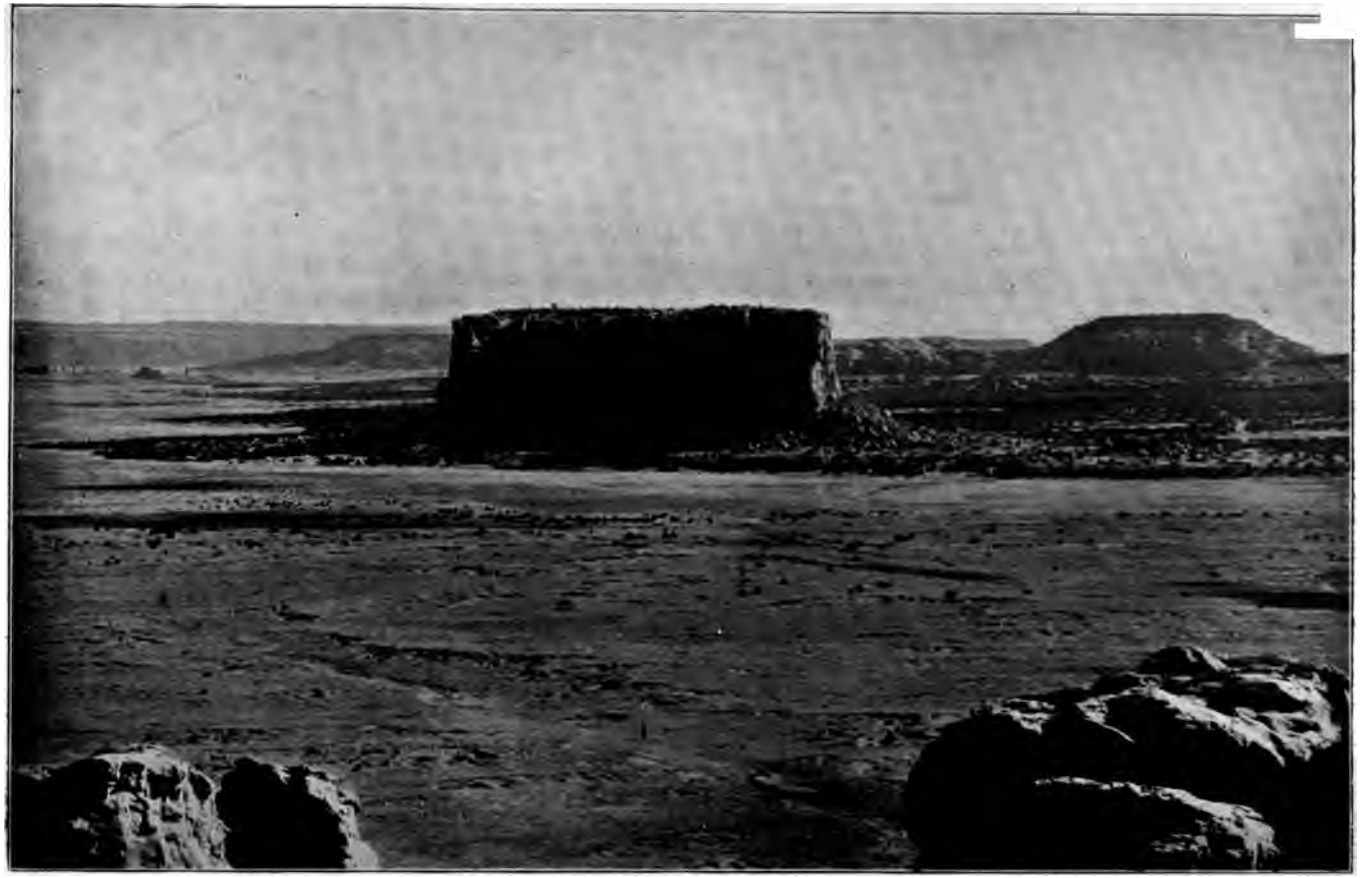
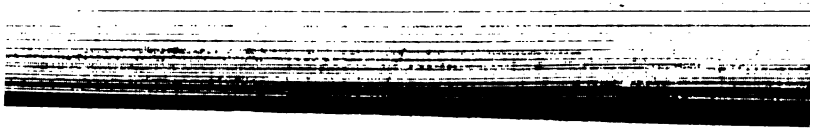
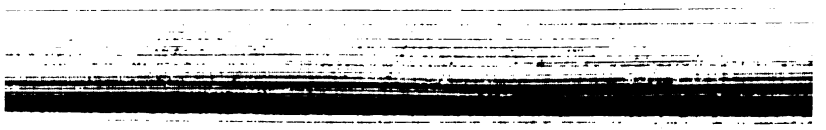


Plate XXIV. — Katzimo, or the Enchanted Mesa, a hill of circumdenudation in horizontal rocks, near Acoma, New Mexico. Height, 430 feet.





I. Constructive Agencies and the Forms They Produce.*

Subaqueous forms.

Widespread deposits.

Deltas. (See page 52.)

Bars. (See page 74.)

Barrier beaches. (See page 76.)

Spits. (See page 74.)

Emergent forms.

Transformation of deltas, bars,† barriers, and spits into dry land.‡

Case of Interlaken; Gulf of California.

A delta on a rising shore.

Silting up of fjords.

Example: Oceanside, California.

Silting up of lakes; salt marshes and fresh-water marshes.§

Formation of storm beaches; coral islands.

Subaërial forms.

Æolian deposits.

Volcanic ejectamenta.

Cinder cones.

Near Flagstaff, Arizona; in San Bernardino county, Cal.

II. Deformation, or Modifying Agencies.

Folding.
Faulting.*

III. Destructive Agencies.

I. Atmosphere, by means of —
   1. Atmospheric moisture.
   2. Winds.
   3. Changes of temperature.

II. Water in form of —
   1. Rain.
   2. Springs.
   3. Streams.
   4. Waves.
   5. Glaciers.
   6. Tidal currents.†

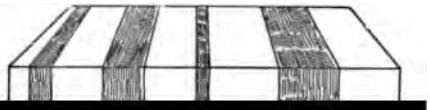
The Forms Produced by Destructive Agencies, and the Factors Determining Them.

The forms produced by destructive agencies, other things being equal, depend upon several controlling factors, which may act alone or in combination.‡

Controlling Factors.

I. *The character and alternation of the rocks.*

Erosion avoids the hard and seeks the softer rocks.



Influence of the varying character of sediments on the continuity of ridges and valleys.

Origin of "pulpit rocks," "chimney rocks," "table rocks," "bottle rock."* (See Fig. 98.)

Exceptional character of the Tepee buttes.†

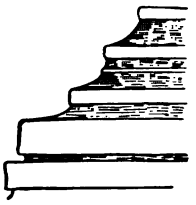


Fig. 94.—Profile of bench-and-bluff topography yielded by alternate hard and soft beds.

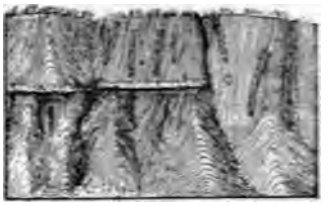


Fig. 95.—A bluff of homogeneous soft beds with a single bed of hard rock. (Harris.)

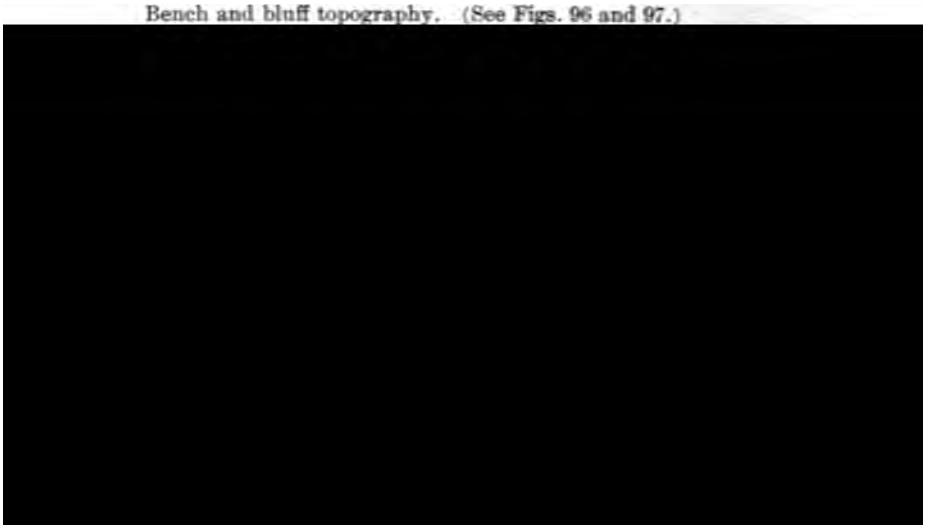
Fig. 96.—Bench-and-bluff topography in a region of horizontal beds. (Simonds.)

II. *The geologic structure or position of the beds.*

Influence of the slope of the beds on the character of the topography.

Topography of horizontal beds.

Bench and bluff topography. (See Figs. 96 and 97.)



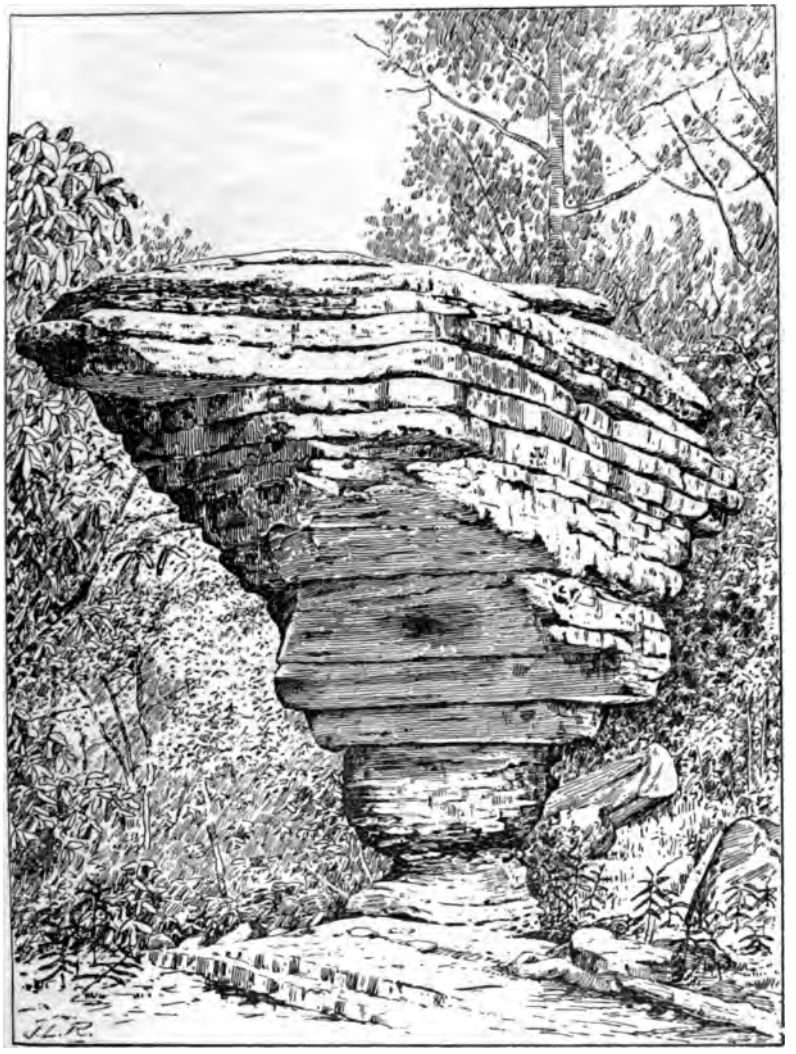


Fig. 98.—A "pulpit rock," left by the removal of the adjacent horizontal strata. (Hopkins.)

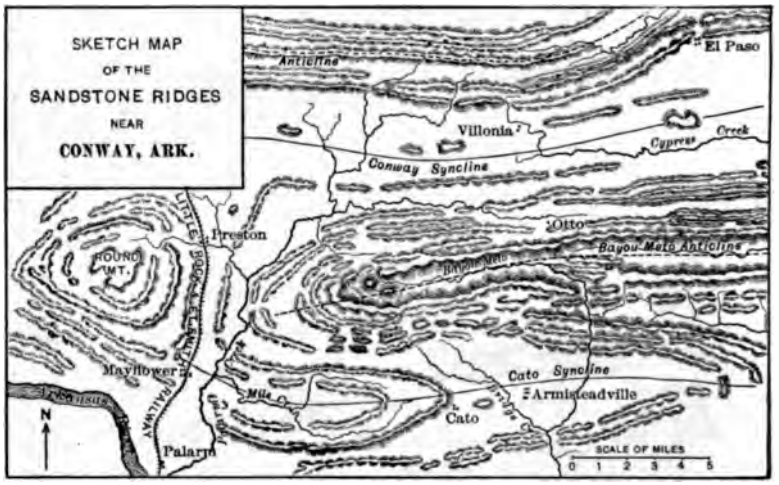


Fig. 99.—Sketch map showing the relation of folded and denuded beds of rock to topography. (Means.)

Topography of folded beds.*

Arkansas.†

Colorado.

Seashore topography varying with the position of the beds in relation to the waves.

Topography of eruptive dikes.‡

Influence of dip on the lateral movements of streams. (See page 354.)

III. *Jointing or fracturing of the rocks.*

Fig. 100.—The "hogbacks" at Morrison, Colorado. The Rocky Mountain range is on the right and the rocks dip eastward away from it.

V. *Climatic conditions.*

Minor topographic features mostly carved by water.

Regions without water subject to little or no change from this cause.

Blown sands of arid regions.

[redacted]

Fig. 100.—The "hogbacks" at Morrison, Colorado. The Rocky Mountain range is on the right and the rocks dip eastward away from it.

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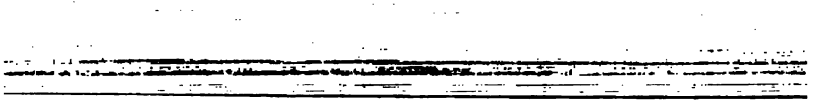


4. Glaciation filling old depressions, scooping out basins, and compelling a new drainage.*
   Moraines damming water in valleys.
   Donner lake.
   Seattle lake.
   Kettle moraine region of Wisconsin and Minnesota.
5. Depression carrying the region beneath the sea.
   The origin of fjords and harbors.†

VII. *The primitive drainage.*

Sinking of land beneath the sea, and the deposition of new beds upon the old topography.

When such areas are re-elevated the drainage of the new surface is determined by general slope and local accidents.

Cutting their channels downward, the streams reach and uncover the buried topography.

The channels are already determined, however.

Such drainage is said to be *superimposed*.

In the main, it is often quite independent of the geologic structure in which it ultimately flows.

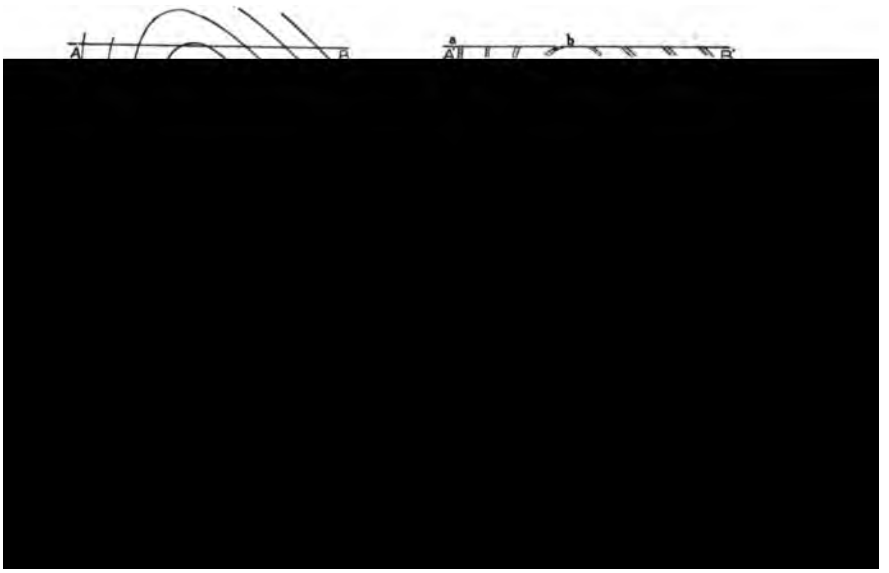
There is a tendency, however, for such drainage to come more and more under the influence of the geology.

VIII. *The length of time the region is exposed to erosion.*

Erosion attacks all land surfaces.

It follows that the longer these surfaces are exposed to erosion, the more they are eroded.

Topography of any area, therefore, changes constantly.



Waterfalls are new topographic features, and must disappear in time.
In general, there is a tendency to smooth down irregularities, and to reduce all to a common low level.
Peneplains or base-levels of erosion.*
The geographical cycle.†

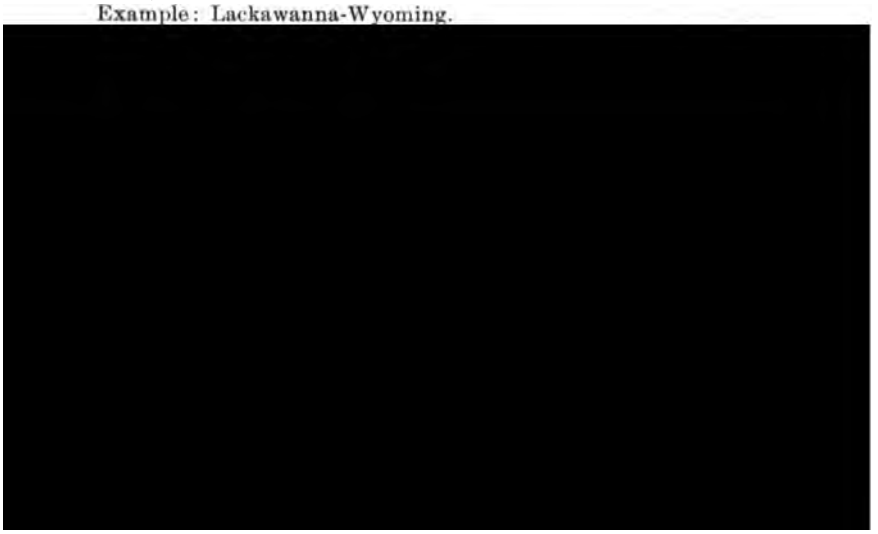
IX. *The nature and working methods of the eroding agency.*
Erosion is done mostly by water and ice in motion.
Erosion done by water tends to cut deep, narrow gullies and gorges on the land, and to undercut sea and lake shores, and to spread out silts over flood-plains and sea-bottoms.
Erosion by ice tends to round off small surface irregularities, while its load is left in the form of moraines.
Erosion in arid regions by isolation and deflation.‡

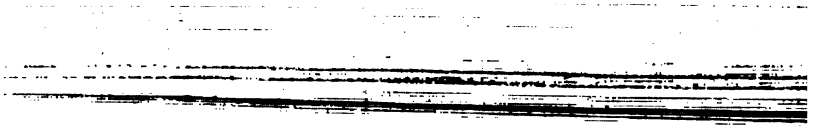
Valleys.

General forms.
1. V-shaped and inverted-A-shaped.
2. U-shaped.
3. With gently sloping sides.

Valley-Forming Agencies.

1. *Erosion.*
Most of our narrow valleys, cañons, gulches, gorges, ravines, etc., have been made by this agency.
These are mostly steep-sided.
Examples: Yosemite,§ Tuolumne, Colorado.
The U-shape of valleys often attributed to ice action.‖
2. *Folding.*
Example: Lackawanna-Wyoming.





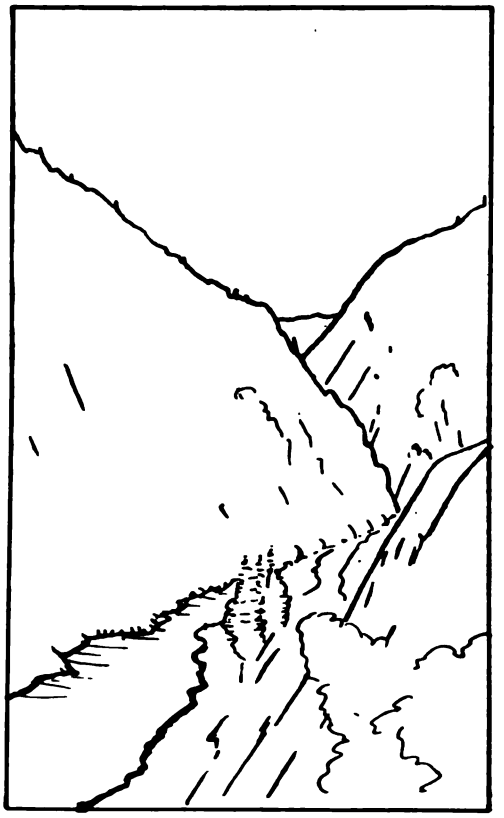
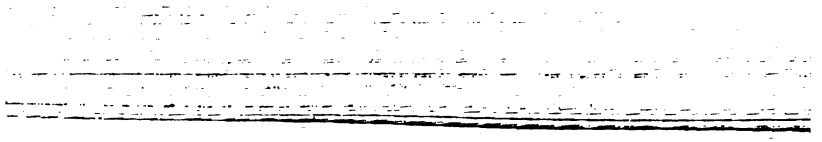


Fig. 102.—The glaciated narrow cañon of the Tuolumne river west of Poopenaut valley, Sierra Nevada Mountains. (Turner.)



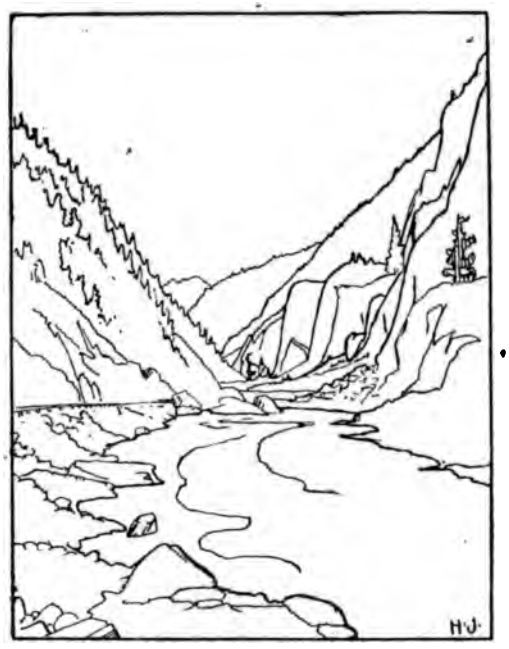


Fig. 104.—Profile of the Animas cañon below Silverton, Colorado. This gorge was filled with ice during the glacial epoch. (Macfarlane.)

Fig. 105.—Profile of the V-shaped Animas cañon two miles below Silverton, Colorado. (Macfarlane.)

AGENCIES MODIFYING VALLEYS.

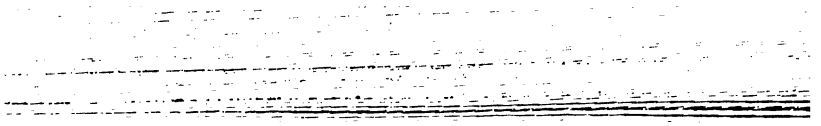
I. Ice erosion and moraines.
   Examples: Yosemite, Lackawanna.
II. Filling in when dammed up.
   Examples: Calaveras, American, Sierra.

Lakes.*

Lake basins originate in some of the following ways:

1. Scooping out of basins by glaciers.†
2. Damming back the waters by —
   a. Landslides.‡
   b. Existing glaciers.§
   c. Moraines left across valleys.
      Lake Chelan in northern Washington is 50 miles long, and from a half to one mile wide, 1,400 feet deep in the middle, is dammed at its lower end by a moraine.‖
      Moraine-dammed lakes in Norway.¶
   d. Igneous outflows across the drainage.
      Nicaragua.**
      Tahoe.††
   e. Faults rising across the drainage.
   f. Shore accumulations, or *cordon littoral*.‡‡
   g. Sand-dunes.

* Les lacs de Jura. Par Ant. Magnin. Ann. de Géog., 1894, III, 213-226.
Lakes of North America. By I. C. Russell. Boston, 1895.
The English lakes. By H. R. Mill. Geog. Jour., July-Aug. 1895.
Present and extinct lakes of Nevada. By I. C. Russell. Physiography of the United



3. Cutting off of basins by silting up.
   Examples: Salton lake;* Interlaken, Switzerland; Vale of Kashmir.†
4. Shifting of streams.
   Ox-bows of the Mississippi river.
5. Orographic movements.
6. Depressions caused by solution of rocks.
   Sink-holes and ponds of limestone regions of Tennessee, Kentucky, etc.
7. Extinct craters.
   Crater Lake, Oregon.‡
   West side of Mt. Hood.

Generalization: lakes are temporary features, and are constantly being formed and obliterated.

Streams and Their Changes.◊

The age of streams.

Newer than the beds over which they flow.

Importance of initial conditions.

Consequent streams.

Streams whose positions are determined by the slope of a new surface.

Subsequent development depends chiefly upon the geology.

Regions of horizontal rocks.

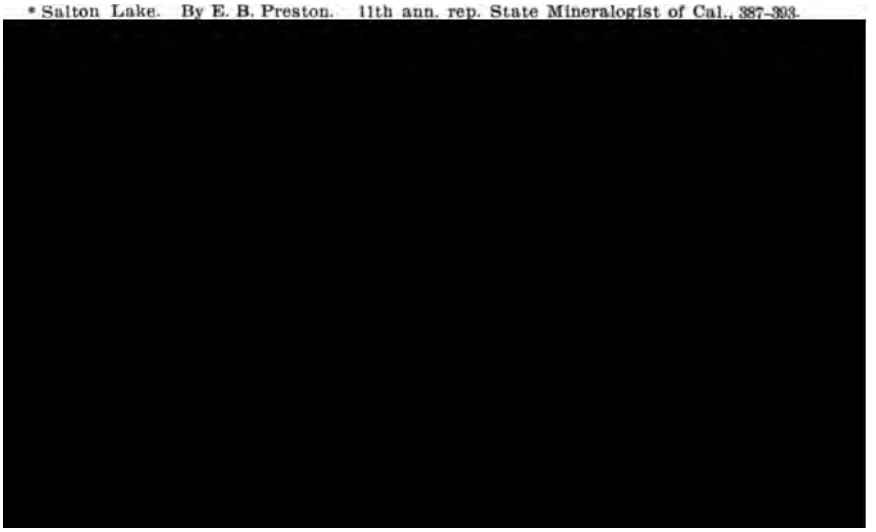
Regions of folded rocks.

Influence of rock joints.‖

Shifting of channels due to dip. (See Figs. 106 and 107.)

Shifting of channels due to choking by debris.¶

* Salton Lake. By E. B. Preston. 11th ann. rep. State Mineralogist of Cal., 387-393.



Superimposed streams.

Superimposed streams have cut down from initial conditions that were developed regardless of the present structure.

Example: southArkansas.

Antecedent streams.

Antecedent streams are those that hold and cut their way through obstacles rising across their courses.

New cycles of erosion are brought about by interruptions of a system of drainage.

The winding of upland streams. Superimposed; developed drainage.*

The winding of lowland streams.

Stream capture.

Fig. 106.—A smooth surface of hard and soft (shaded) inclined beds.

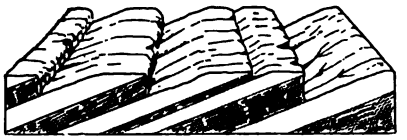


Fig. 107.—The same as Fig. 106 after being subjected to erosion. The streams follow the soft strata.

Fig. 108.—A region of folded beds with the streams following the soft and avoiding the hard ones.

TERRACES.†

Terraces may be produced by—

1. The cutting of waves along a shore.‡
2. The cutting of a meandering stream.§

Why the highest terraces are the oldest.

Why stream terraces are often in

ISLANDS.

Islands of	Destruction	When the sea encroaches on the land, leaving resisting points.
	Construction	Sediments deposited by tides, currents and streams.
	Emergence	Igneous; orographic movements.
	Submergence	Subsidence leaves isolated peaks as islands.

Effects of Topography upon Civilization.*

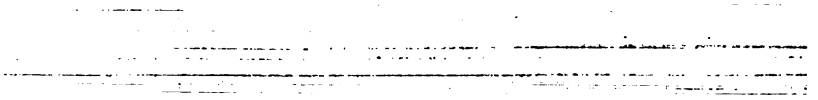
Relations of topography to —

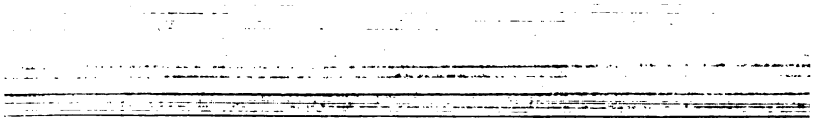
1. Political boundaries.
2. Harbors and marine industries.†
3. Location of cities and manufactures.‡
4. Art.
   Scenery.§
5. Agriculture.
6. Literature.‖

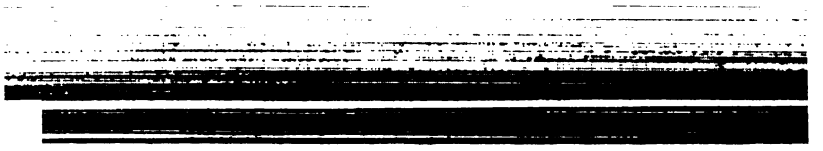
TOPOGRAPHIC MODELS OR RELIEF MAPS.¶

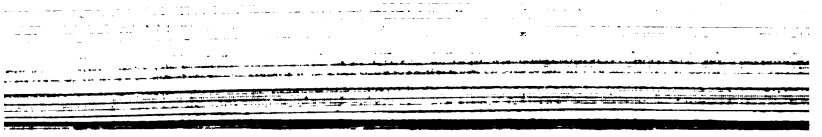
Uses.
Methods of construction.
Materials of the originals.
Materials used for the finished map.
The question of the vertical scale.

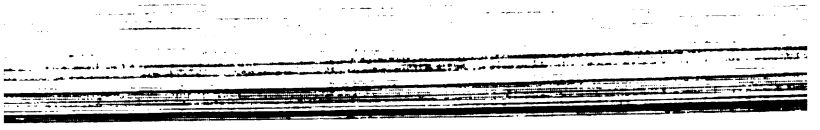
* Nature and man in America. By N. S. Shaler. New York, 1891.
† The geological history of harbors. By N. S. Shaler. 13th ann. rep. U. S. Geol. Surv., part II, 93–209. Washington, 1893.

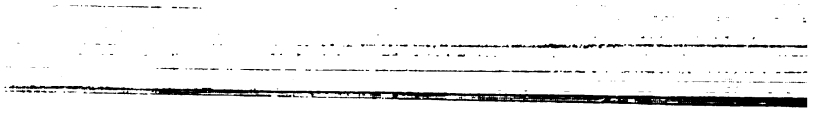


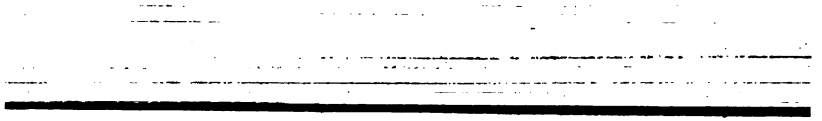


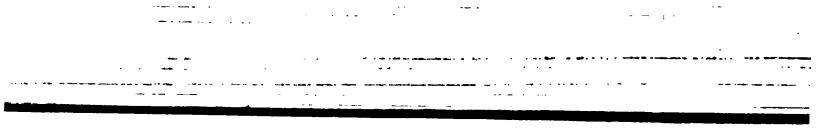


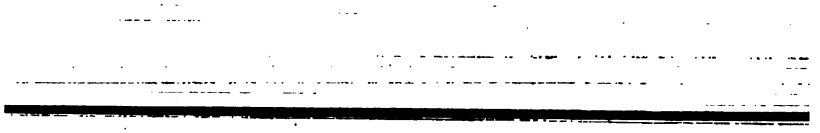


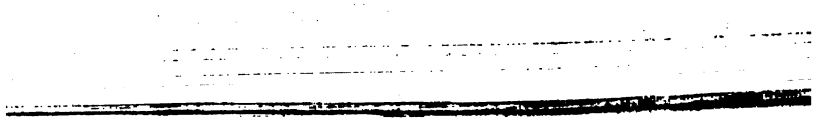


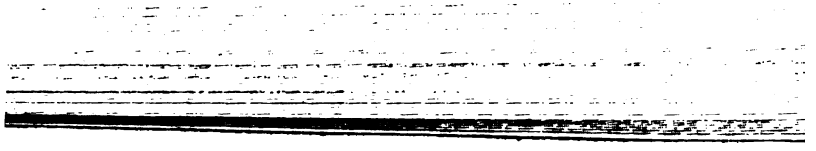


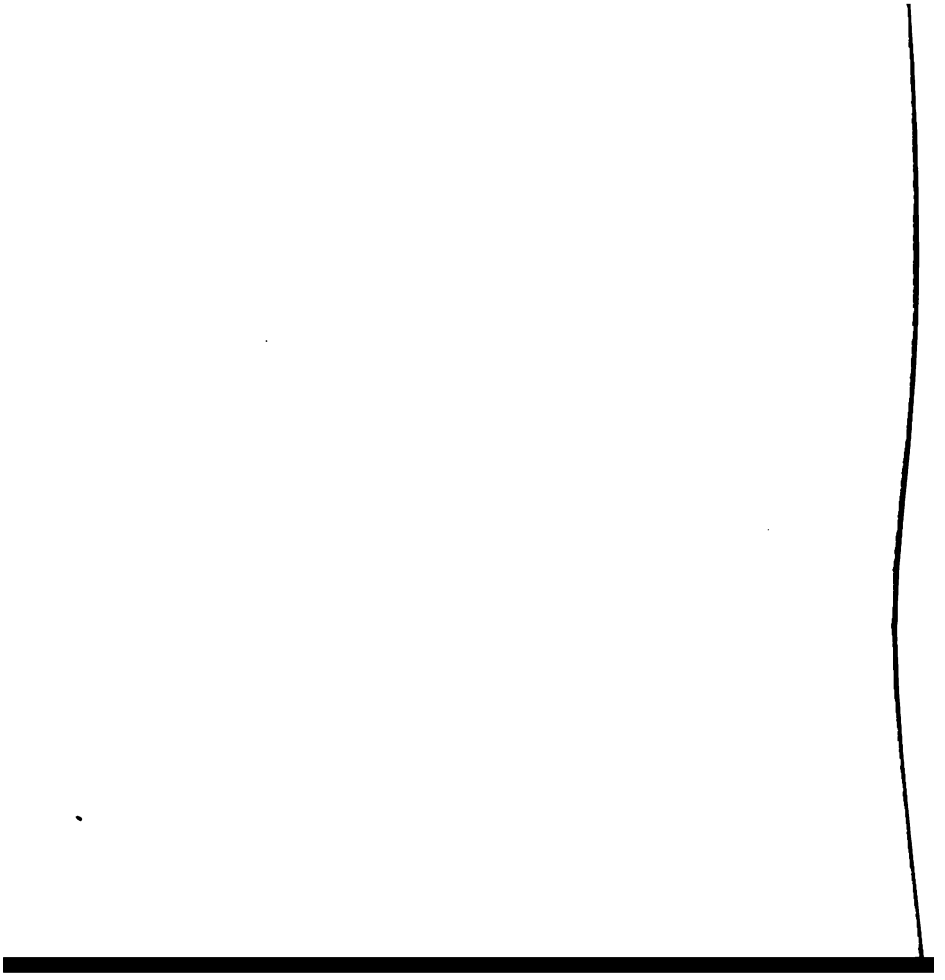


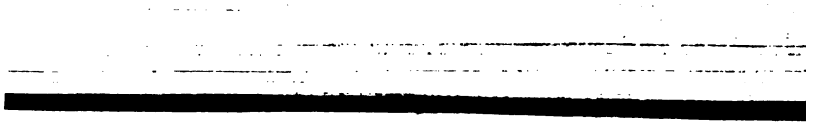


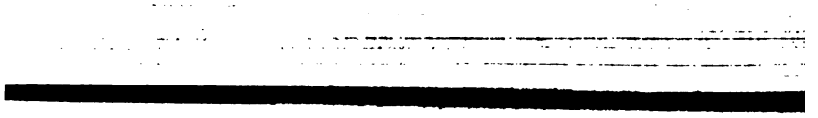


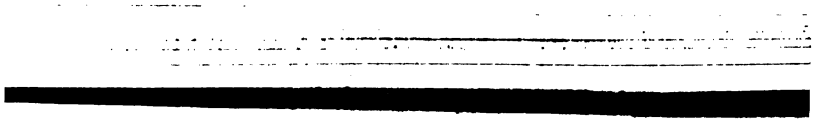


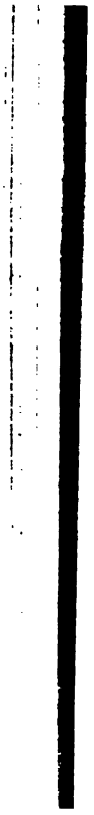


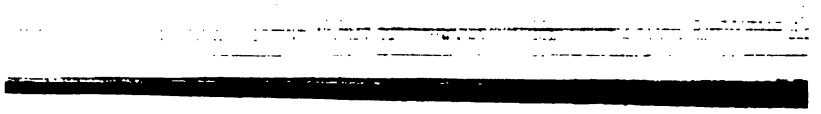


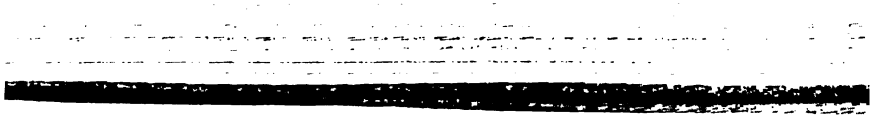












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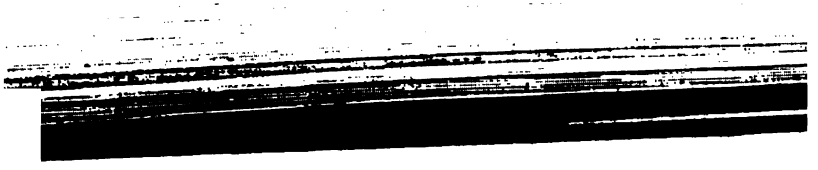

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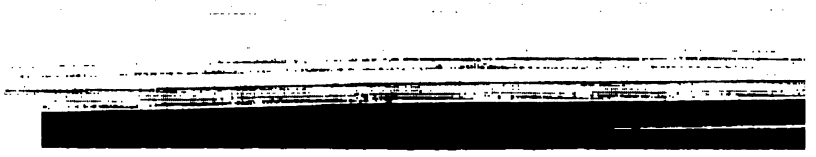

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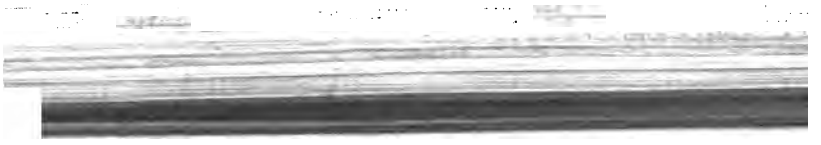

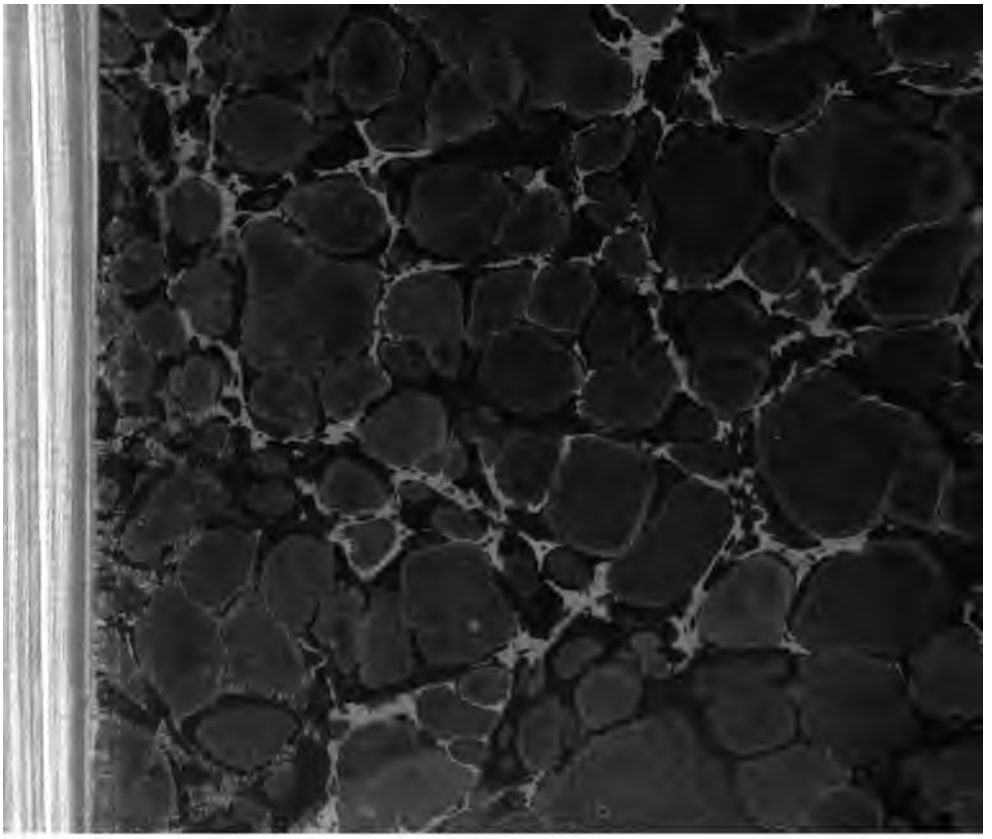

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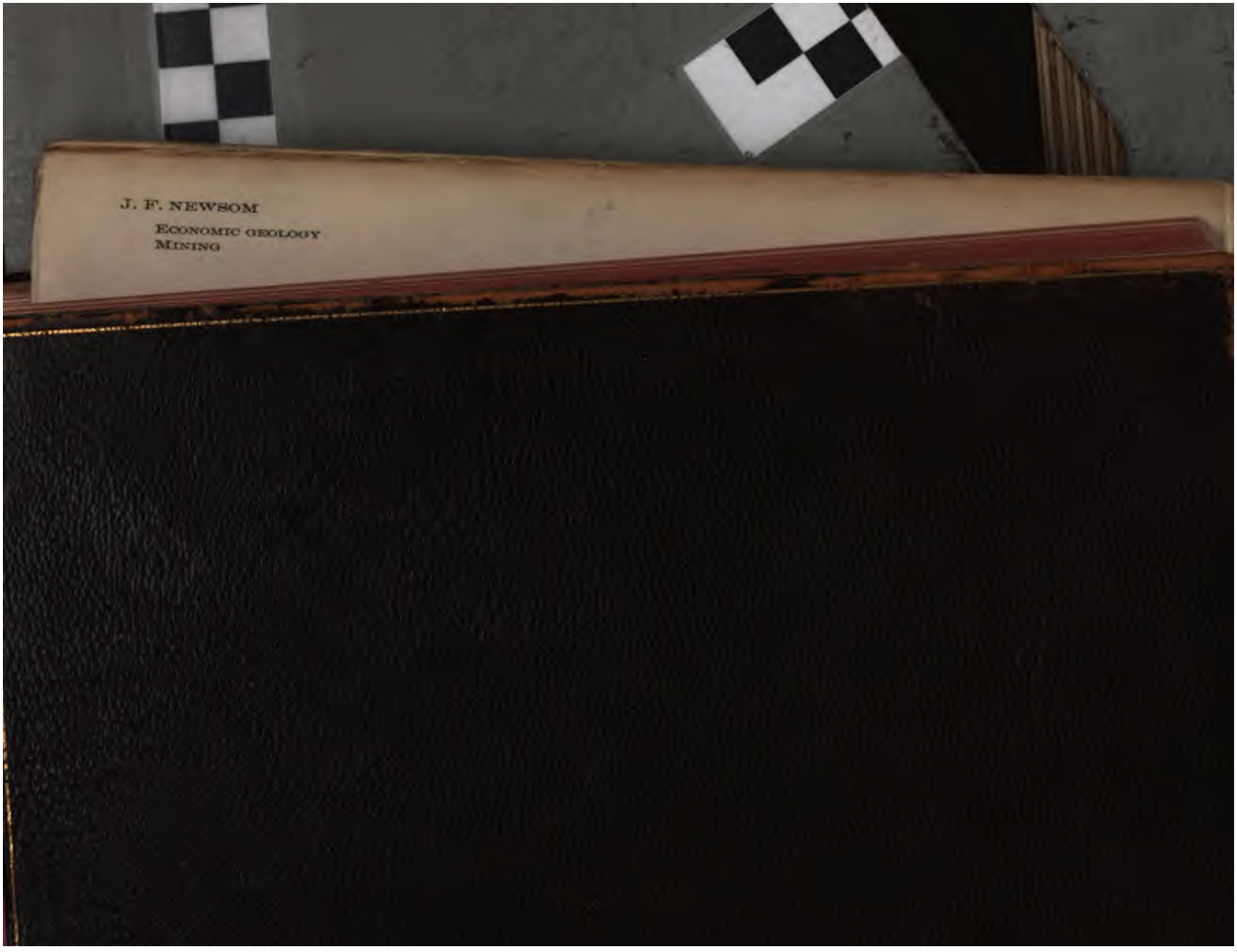
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